The Making of the Chandra X-ray Observatory

December 12, 2003

Martin C. Weisskopf

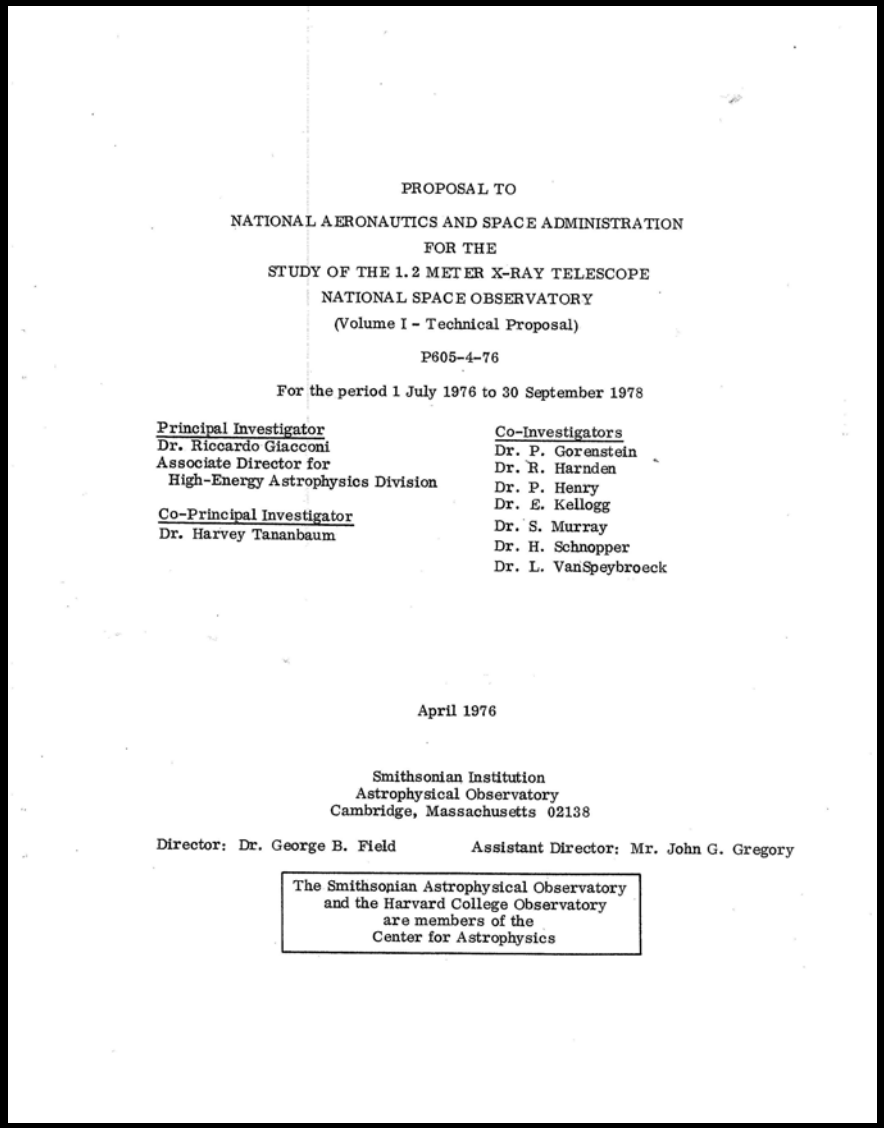
The Magic Formula

SEX + PIG = Chandra

1969

In the beginning …

- 1976 – Proposal was submitted
  - This was the "formal" beginning



PROPOSAL TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOR THE

STUDY OF THE 1.2 METER X-RAY TELESCOPE

NATIONAL SPACE OBSERVATORY

(Volume I - Technical Proposal)

P605-4-76

For the period 1 July 1976 to 30 September 1978

Principal Investigator
Dr. Riccardo Giacconi
Associate Director for
High-Energy Astrophysics Division

Co-Principal Investigator
Dr. Harvey Tananbaum

Co-Investigators
Dr. P. Gorenstein
Dr. R. Harnden
Dr. P. Henry
Dr. E. Kellogg
Dr. S. Murray
Dr. H. Schnopper
Dr. L. VanSpeybroeck

April 1976

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

Director: Dr. George B. Field Assistant Director: Mr. John G. Gregory

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

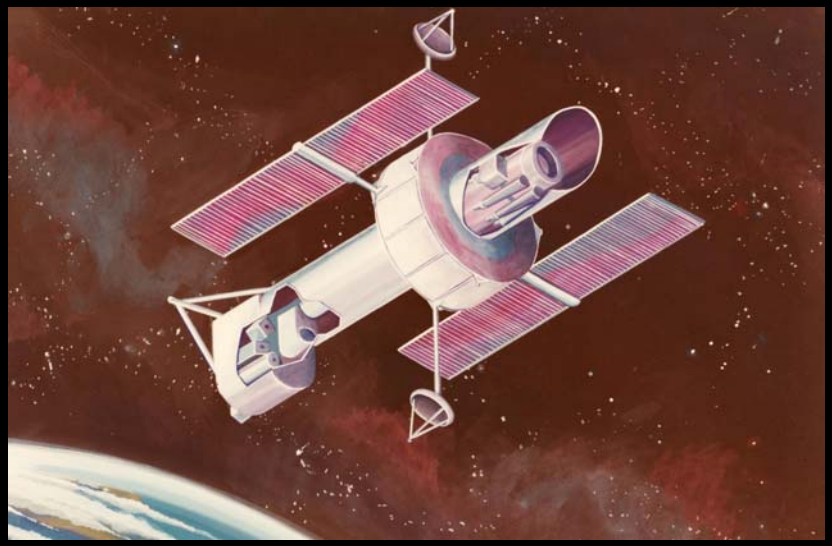
First SWG

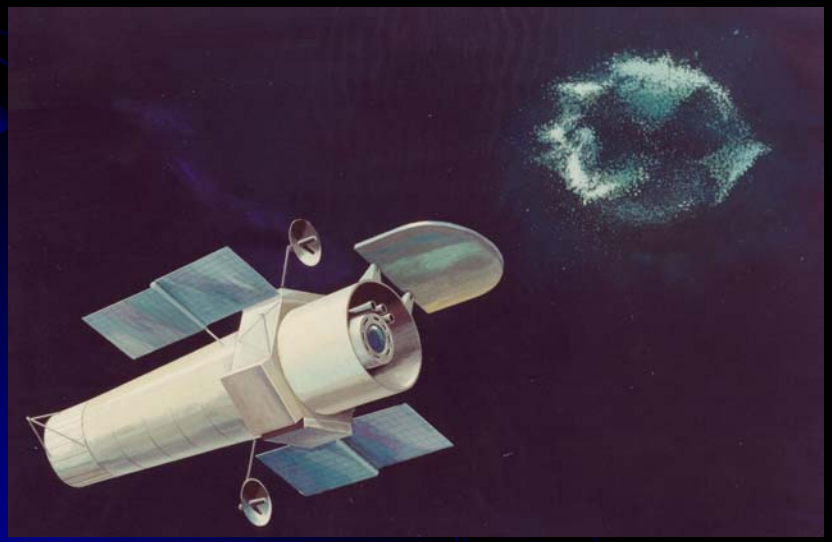
- R. Giacconi – Chmn
- M. Weisskopf – Vice Chmn
- A. Opp (NASA HQ) – Ex Officio
  - E. Boldt (GSFC)
  - G. Clark (MIT)
  - G. Garmire (CIT)
  - R. Novick (Columbia)
  - H. Tananbaum (SAO)
  - K. Pounds (Leicester)
  - S. Bowyer (UCB)
  - A. Davidsen (JHU)
  - B. Krasheur (Wisc)
  - S. Shulman (NRL)
  - A. Walker (Stanford)
  - J. Truemper (MPE)

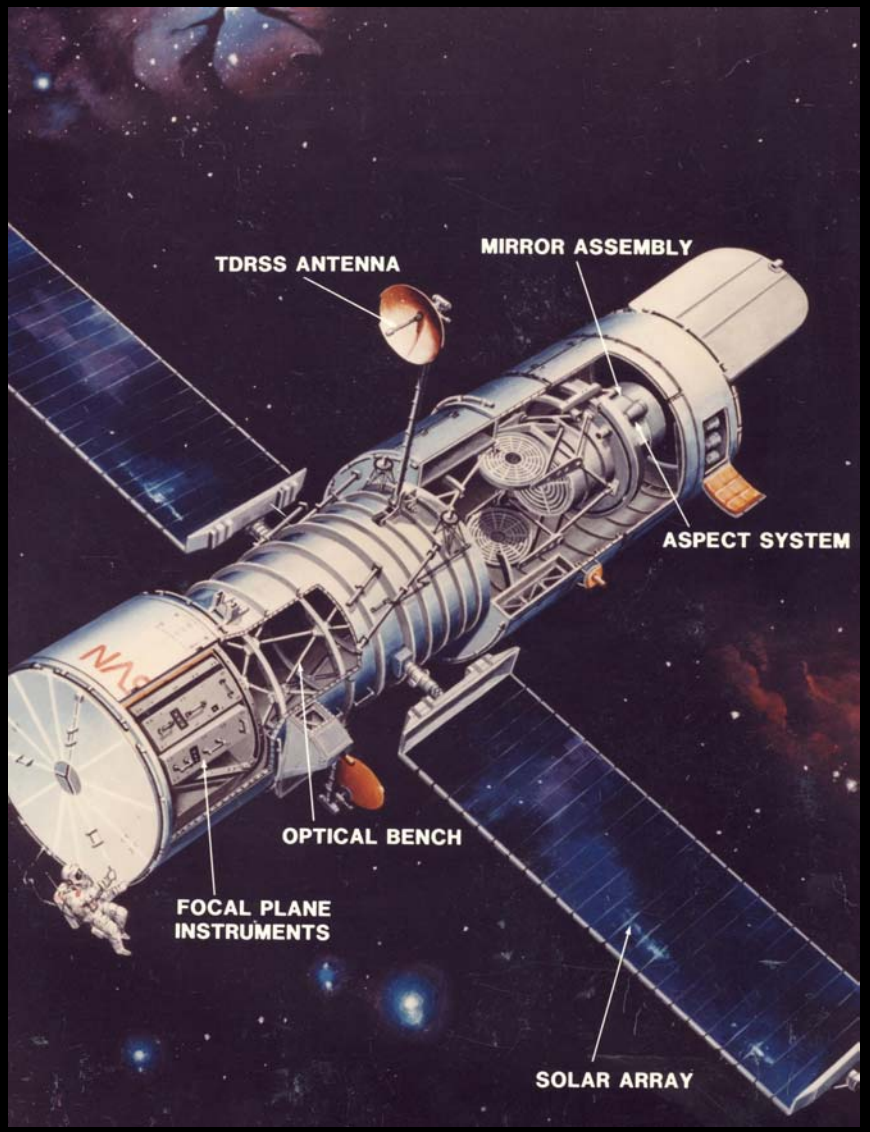
Early Trades

- Moveable Mirror
- Focal Length
- Number of Mirrors
- Diameters of Mirrors
- Aspect Solution
- Calibration
- Payload

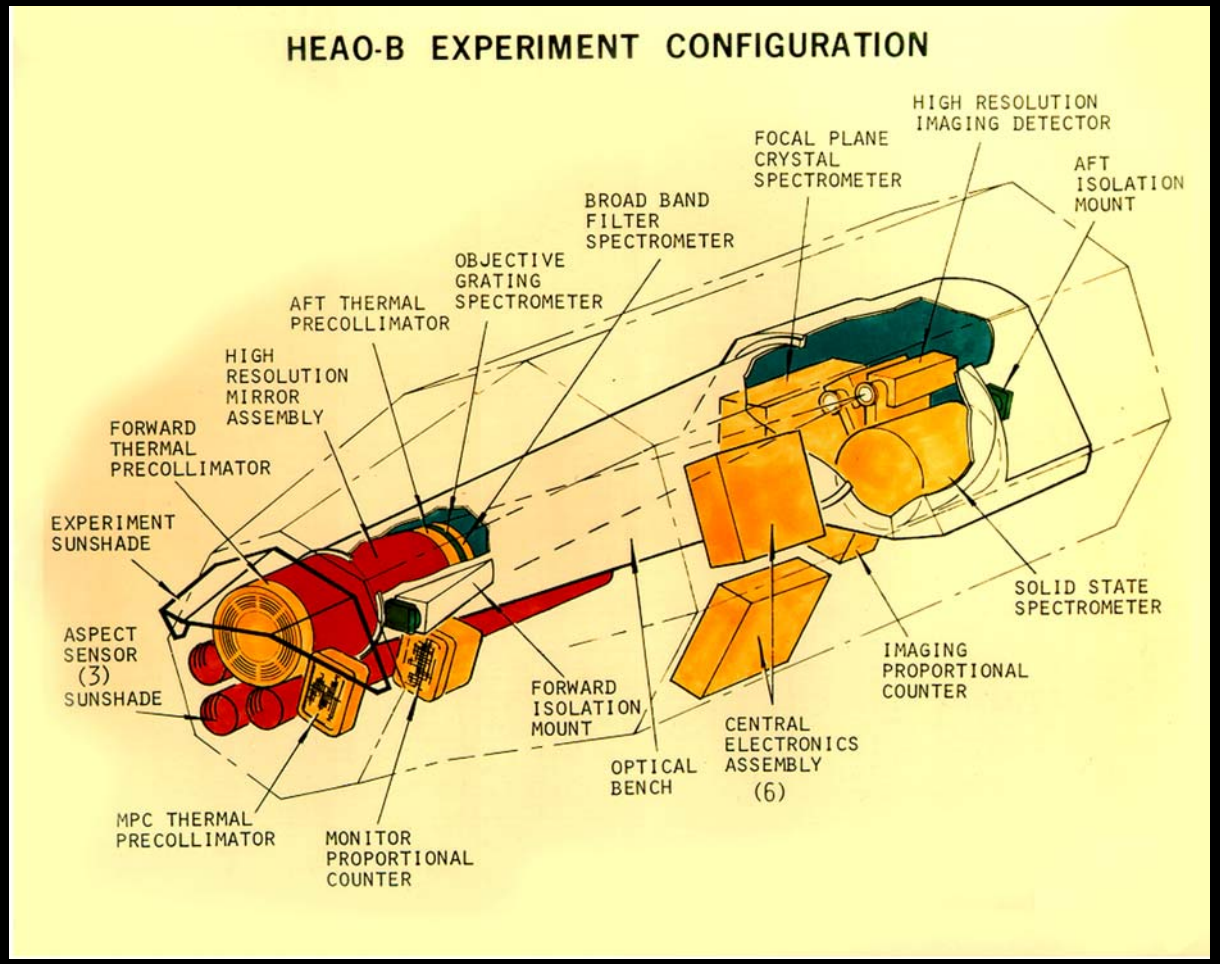
Concepts






TDRSS ANTENNA
MIRROR ASSEMBLY
ASPECT SYSTEM
OPTICAL BENCH
FOCAL PLANE INSTRUMENTS
SOLAR ARRAY

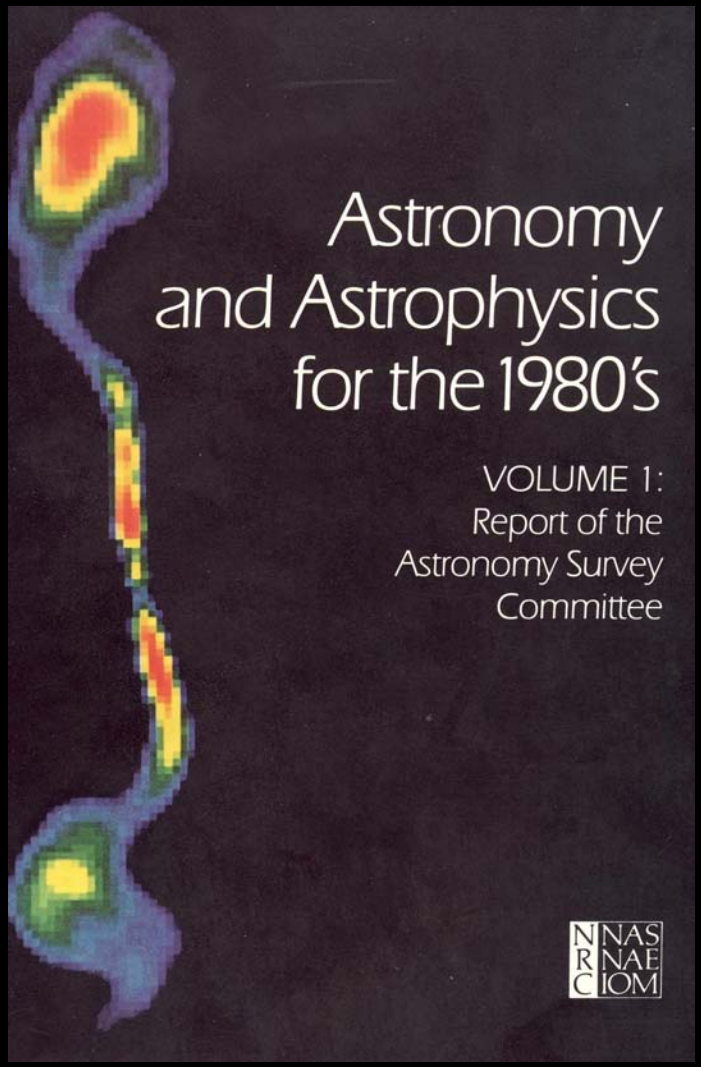
Einstein Observatory - 1979



Decadal Survey - 1981

Major New Programs:

- #1: An Advanced X-Ray Astrophysics Facility (AXAF)

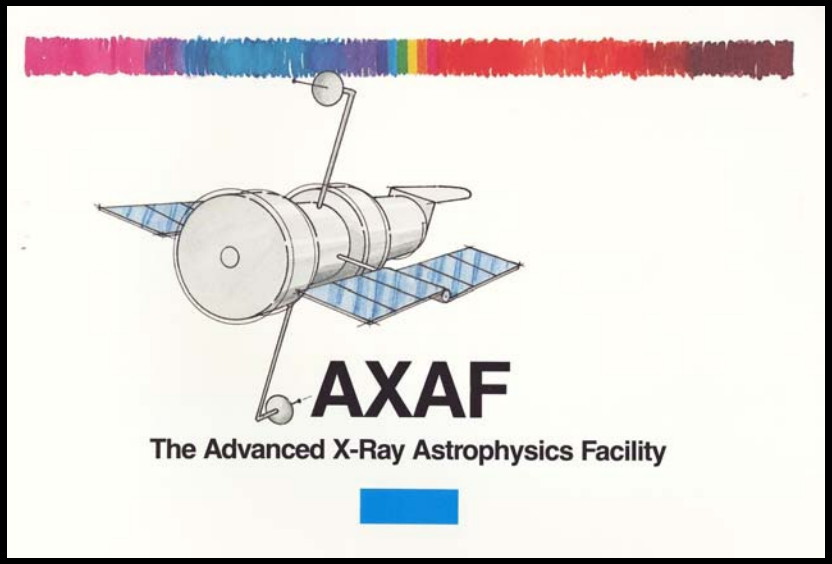


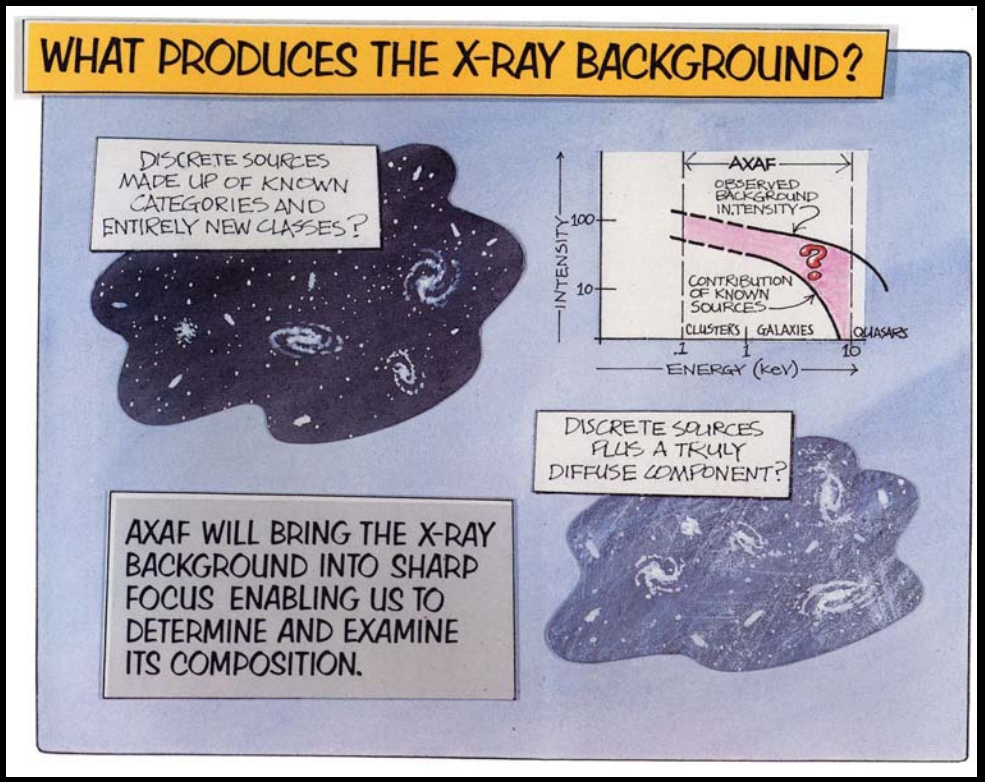
AO (1983): Selection (1985)

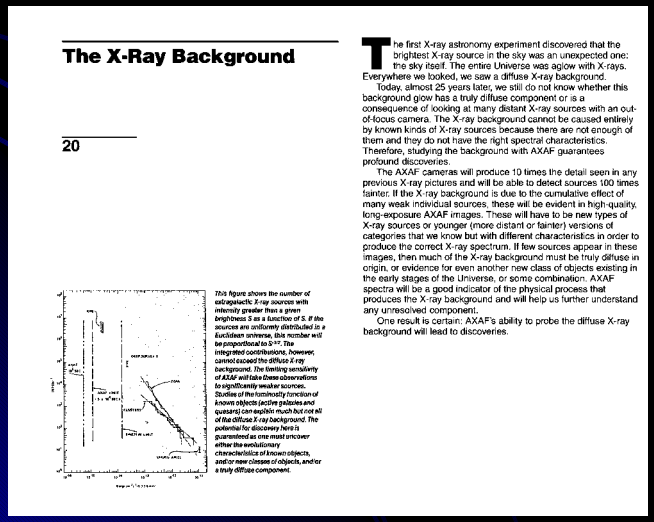
- ACIS – proposed 49 CCDs!
- HRC
- LETG
- HETG
- FPCS – Focal Plane Crystal Spectrometer
  - Removed in 1988
- XRS – X-Ray Calorimeter Spectrometer
  - AXAF-S - 1991
  - ASTRO-E(2) -1993

The Second SWG (1985 –)

Brochure(s) 1986







The X-Ray Background

20

This figure shows the number of extragalactic X-ray sources with intensity greater than a given brightness S as a function of S. If the sources are uniformly distributed in a Euclidean universe, this number will be proportional to $S^{-1.5}$. The integrated contributions, however, cannot exceed the diffuse X-ray background. The limiting sensitivity of AXAF will take these observations to significantly weaker sources. Studies of the luminosity function of known objects (active galaxies and quasars) can explain much but not all of the diffuse X-ray background. The potential for discovery here is guaranteed as one must uncover either the evolutionary characteristics of known objects, and/or new classes of objects, and/or a truly diffuse component.

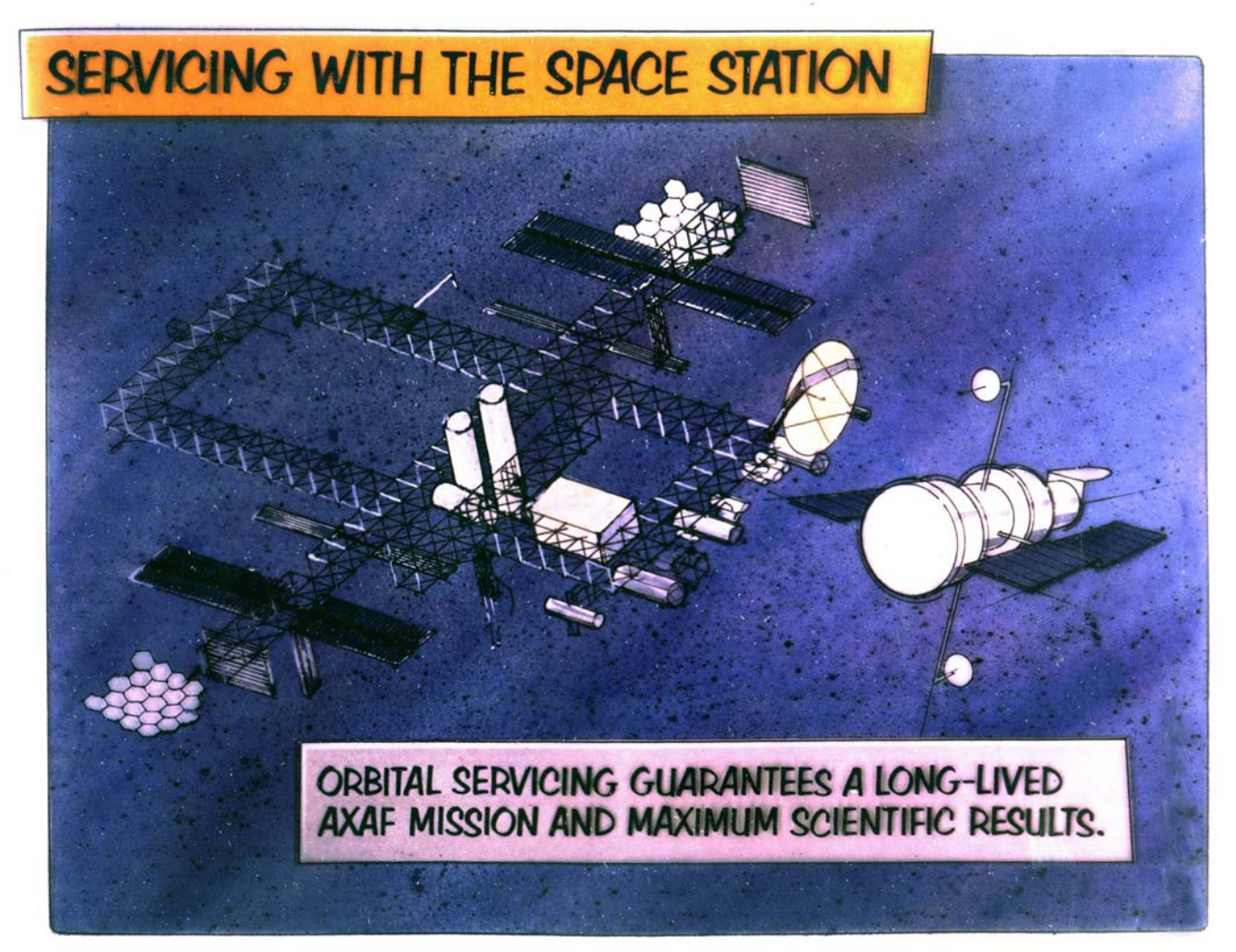
The first X-ray astronomy experiment discovered that the brightest X-ray source in the sky was an unexpected one: the sky itself. The entire Universe was aglow with X-rays. Everywhere we looked, we saw a diffuse X-ray background.

Today, almost 25 years later, we still do not know whether this background glow has a truly diffuse component or is a consequence of looking at many distant X-ray sources with an out-of-focus camera. The X-ray background cannot be caused entirely by known kinds of X-ray sources because there are not enough of them and they do not have the right spectral characteristics. Therefore, studying the background with AXAF guarantees profound discoveries.

The AXAF cameras will produce 10 times the detail seen in any previous X-ray pictures and will be able to detect sources 100 times fainter. If the X-ray background is due to the cumulative effect of many weak individual sources, these will be evident in high-quality, long-exposure AXAF images. These will have to be new types of X-ray sources or younger (more distant or fainter) versions of categories that we know but with different characteristics in order to produce the correct X-ray spectrum. If few sources appear in these images, then much of the X-ray background must be truly diffuse in origin, or evidence for even another new class of objects existing in the early stages of the Universe, or some combination. AXAF spectra will be a good indicator of the physical process that produces the X-ray background and will help us further understand any unresolved component.

One result is certain: AXAF's ability to probe the diffuse X-ray background will lead to discoveries.

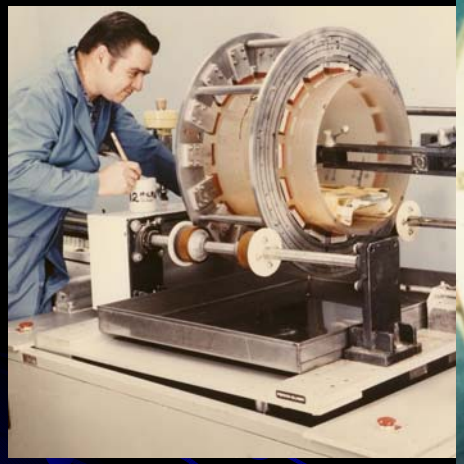
Space Station Appears

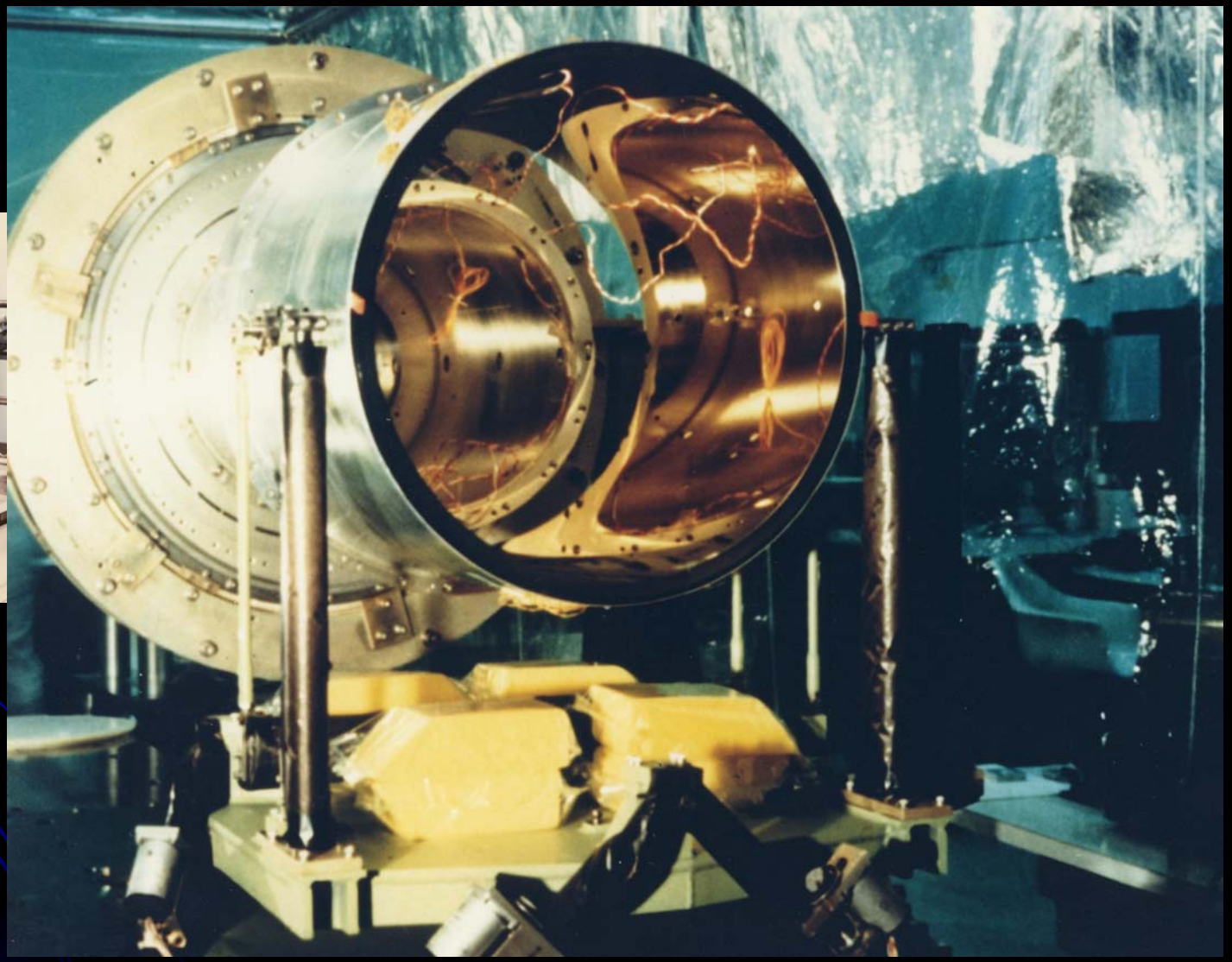


Technology Mirror Assembly

- Single mirror pair
- Scaled (2/3) Version of innermost mirrors
- 6-m focal length
  - Allowed for testing in existing facility
- 0.41-m element length
- 0.42-m diameter
- Gold coated (baseline at the time)

Technology Mirror Assembly

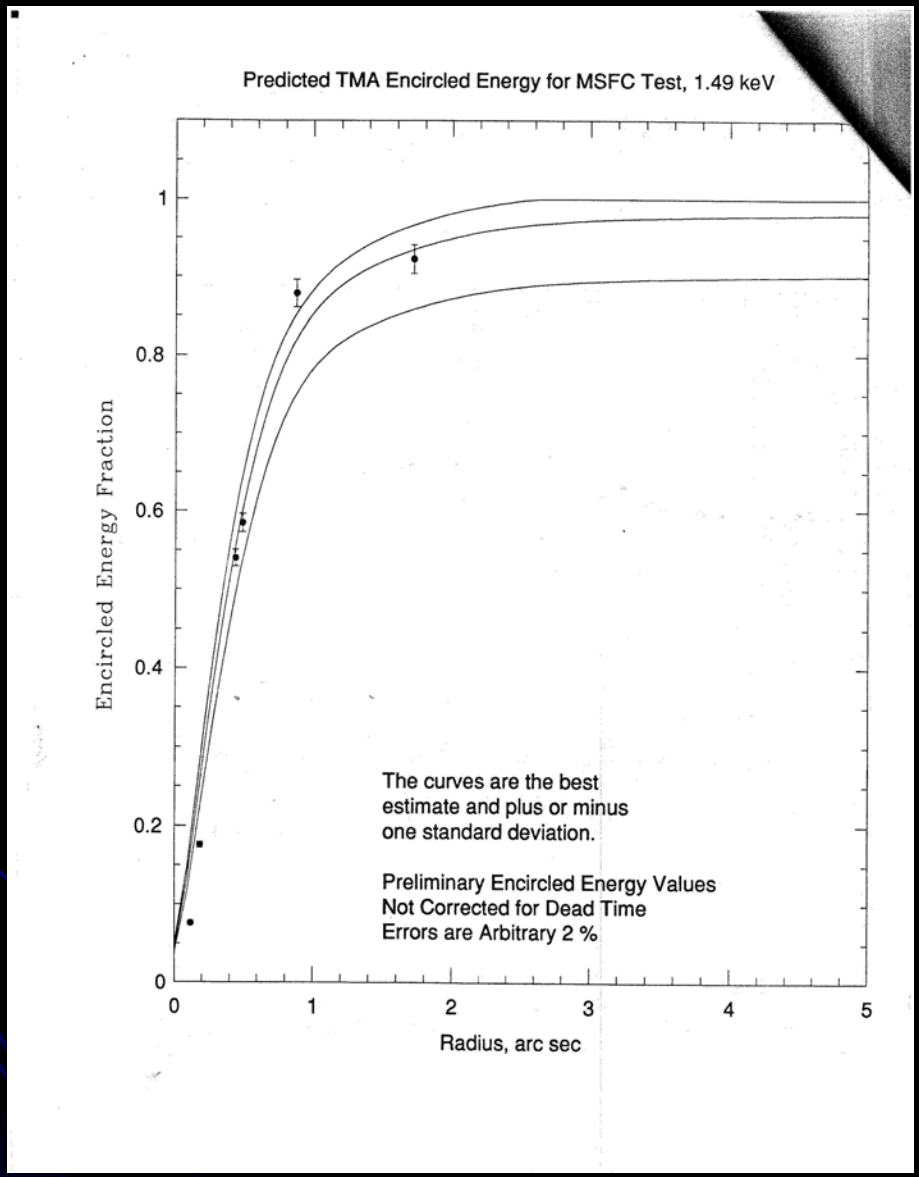




Technology Mirror Assembly

- First delivery July 1985
  - FWHM < 0.5”
  - Near-angle scatter (ripple @ 0.7 mm)
- Second delivery Jan 1989
- Final results were great
  - E.g. FWHM from 0.36” – 0.68”
  - Encircled energy as predicted

TMA-2: Encircled Energy



Intermediate Milestones

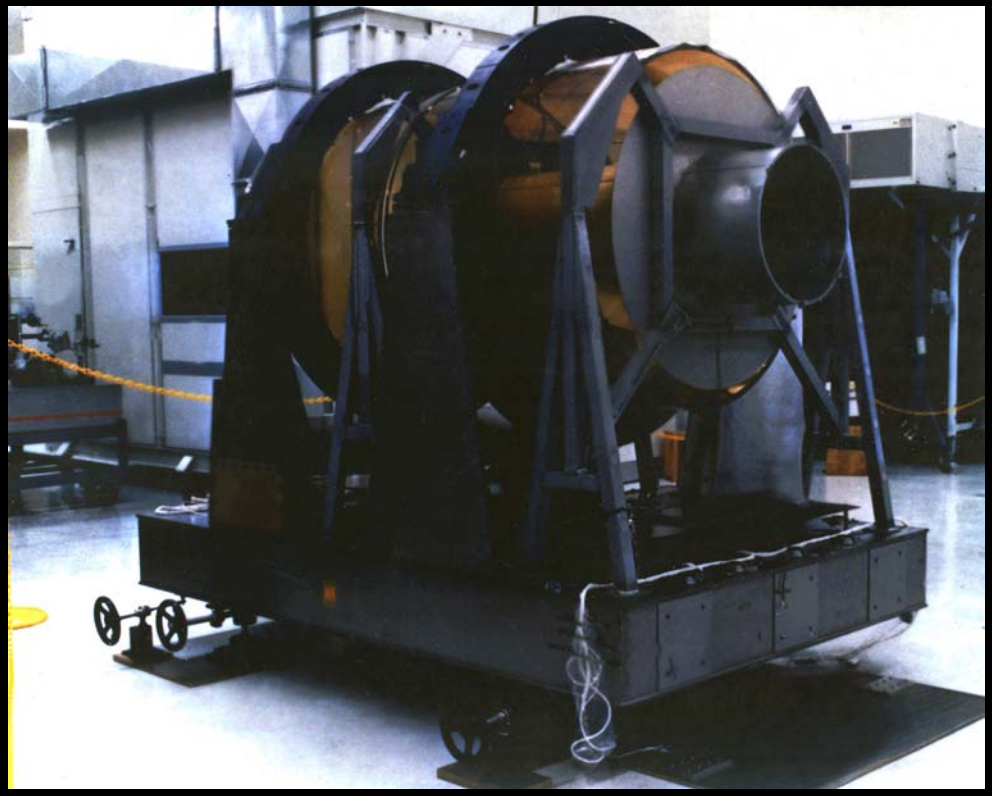
- Initiate purchase of Mirror blanks 1987

Intermediate Milestones

- Prime contractor selection – 1988
- “New Start” - 1988
- Selection of the Science Center – 1991
- The “VETA” program - 1991
  - Verification Engineering Test Article
  - “The tall pole in the tent”

VETA 1991

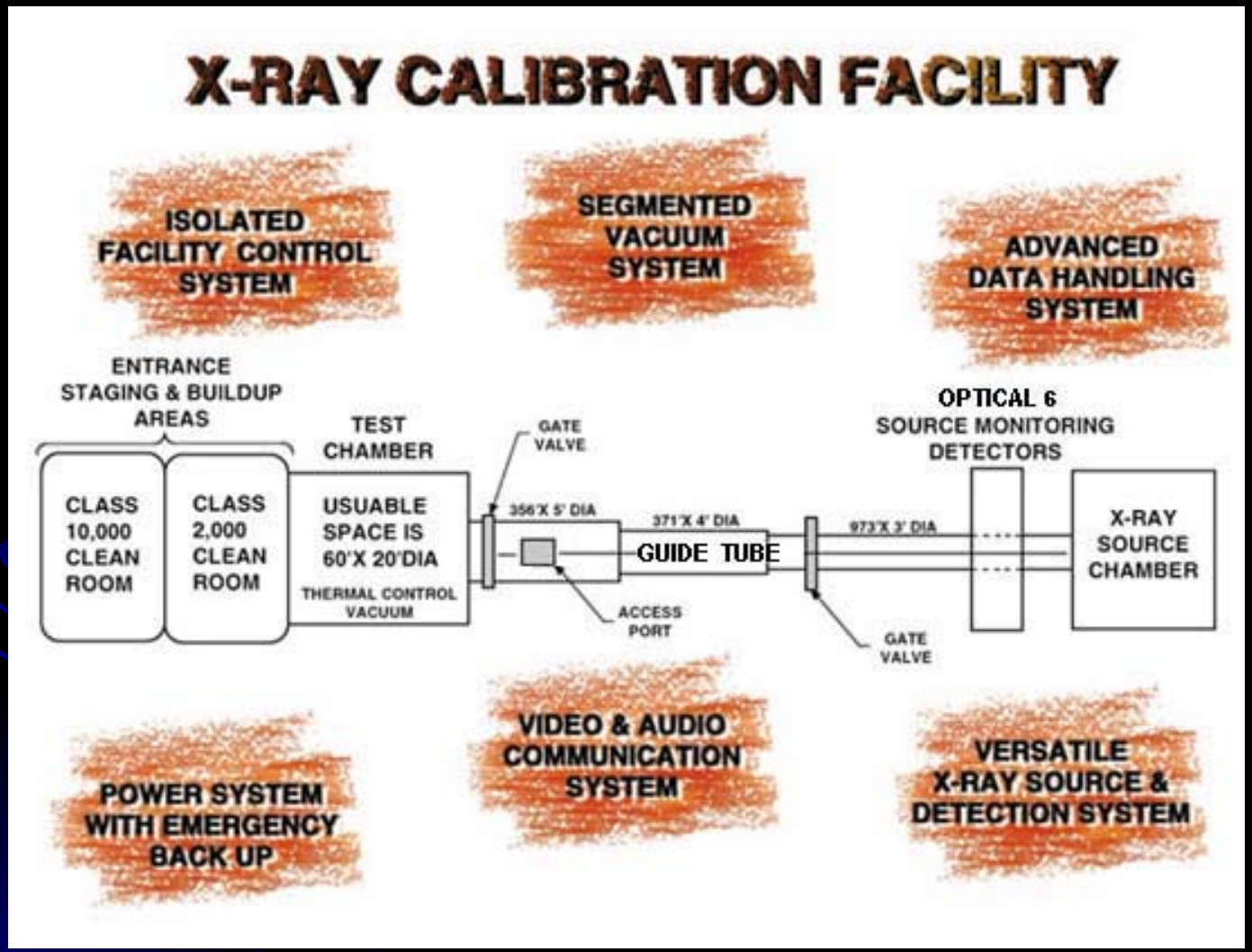
- P1/H1 – uncoated and uncut



- Needed Test Facility at least one year earlier than scheduled

XRCF

XRCF

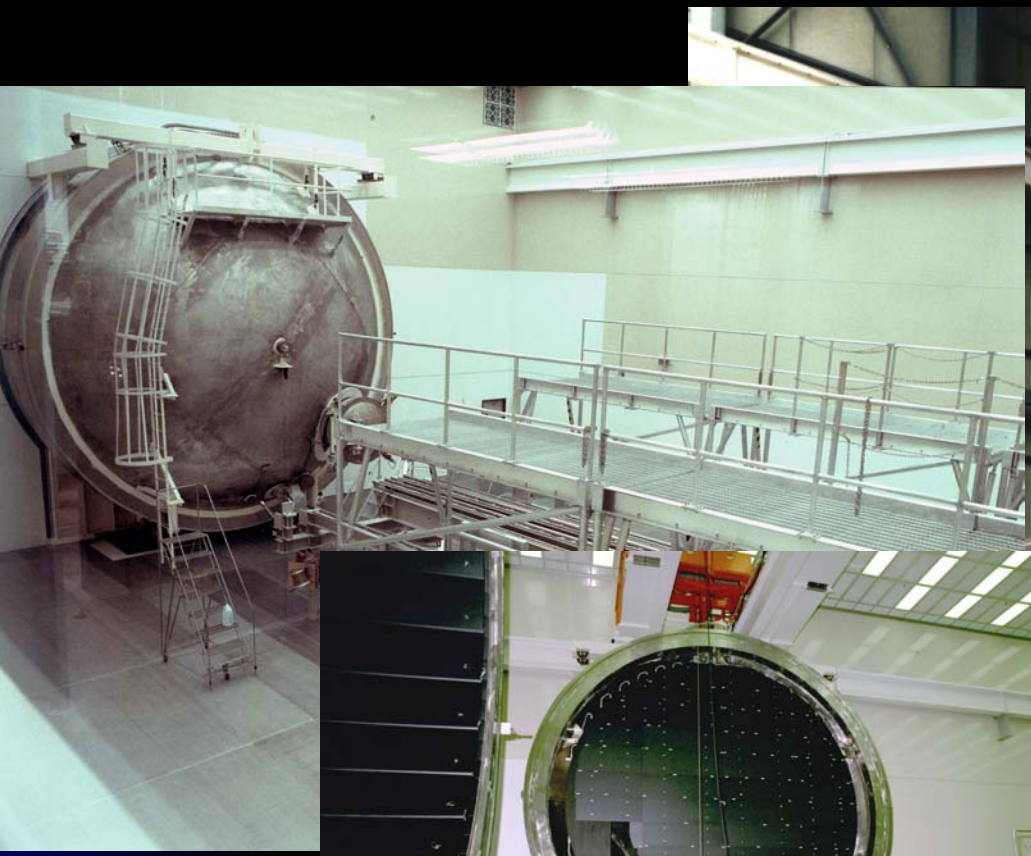

X-RAY CALIBRATION FACILITY
ISOLATED FACILITY CONTROL SYSTEM
SEGMENTED VACUUM SYSTEM
ADVANCED DATA HANDLING SYSTEM
ENTRANCE STAGING & BUILDUP AREAS
CLASS 10,000 CLEAN ROOM
CLASS 2,000 CLEAN ROOM
TEST CHAMBER
USUABLE SPACE IS 60'X 20'DIA
THERMAL CONTROL VACUUM
GATE VALVE
356'X 5' DIA
371'X 4' DIA
GUIDE TUBE
ACCESS PORT
973'X 3' DIA
GATE VALVE
OPTICAL 6 SOURCE MONITORING DETECTORS
X-RAY SOURCE CHAMBER
POWER SYSTEM WITH EMERGENCY BACK UP
VIDEO & AUDIO COMMUNICATION SYSTEM
VERSATILE X-RAY SOURCE & DETECTION SYSTEM

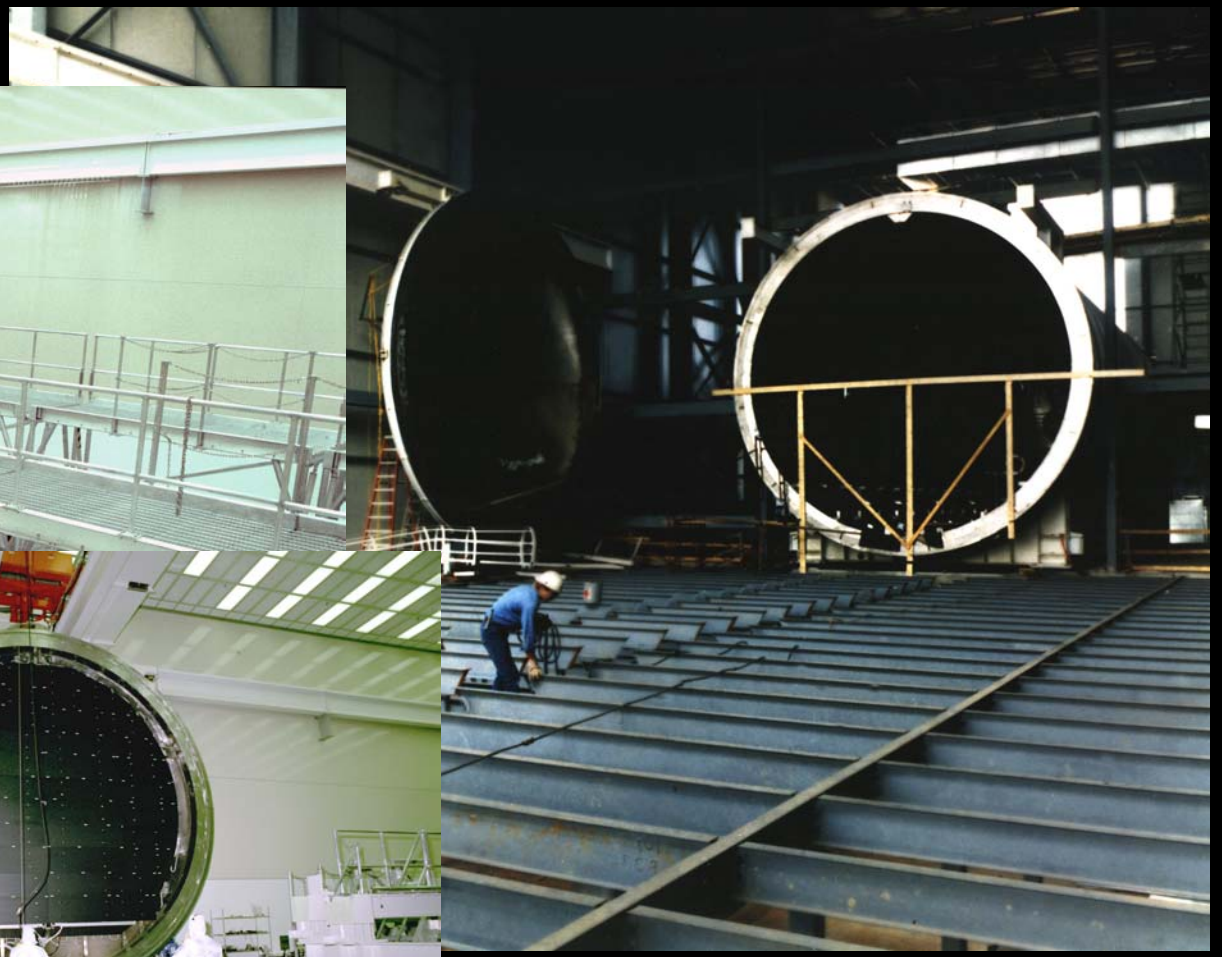
XRCF

XRCF

XRCF

XRCF





XRCF

XRCF

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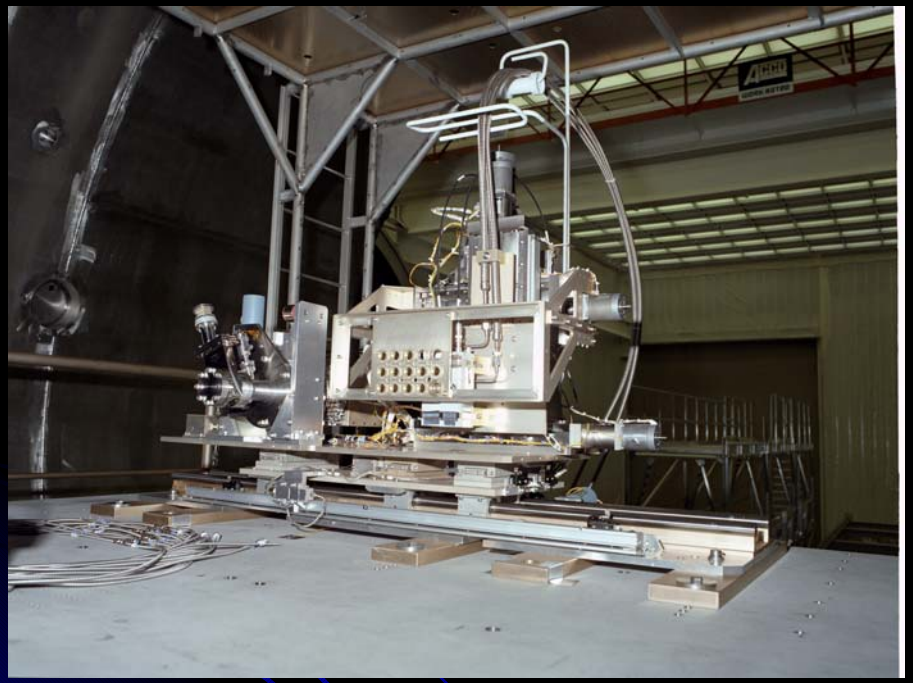
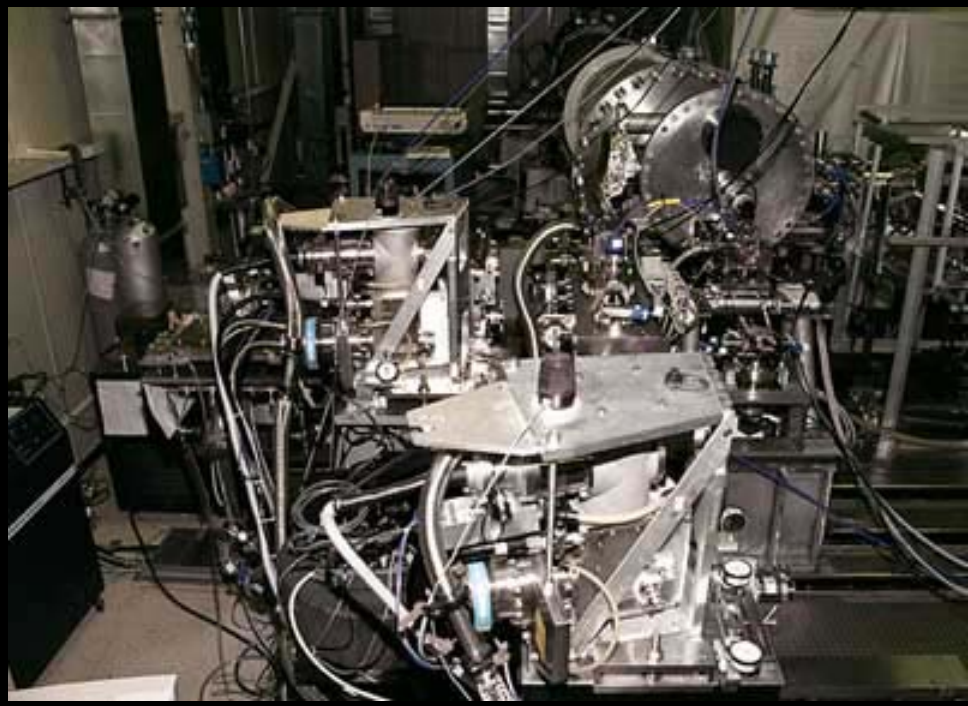
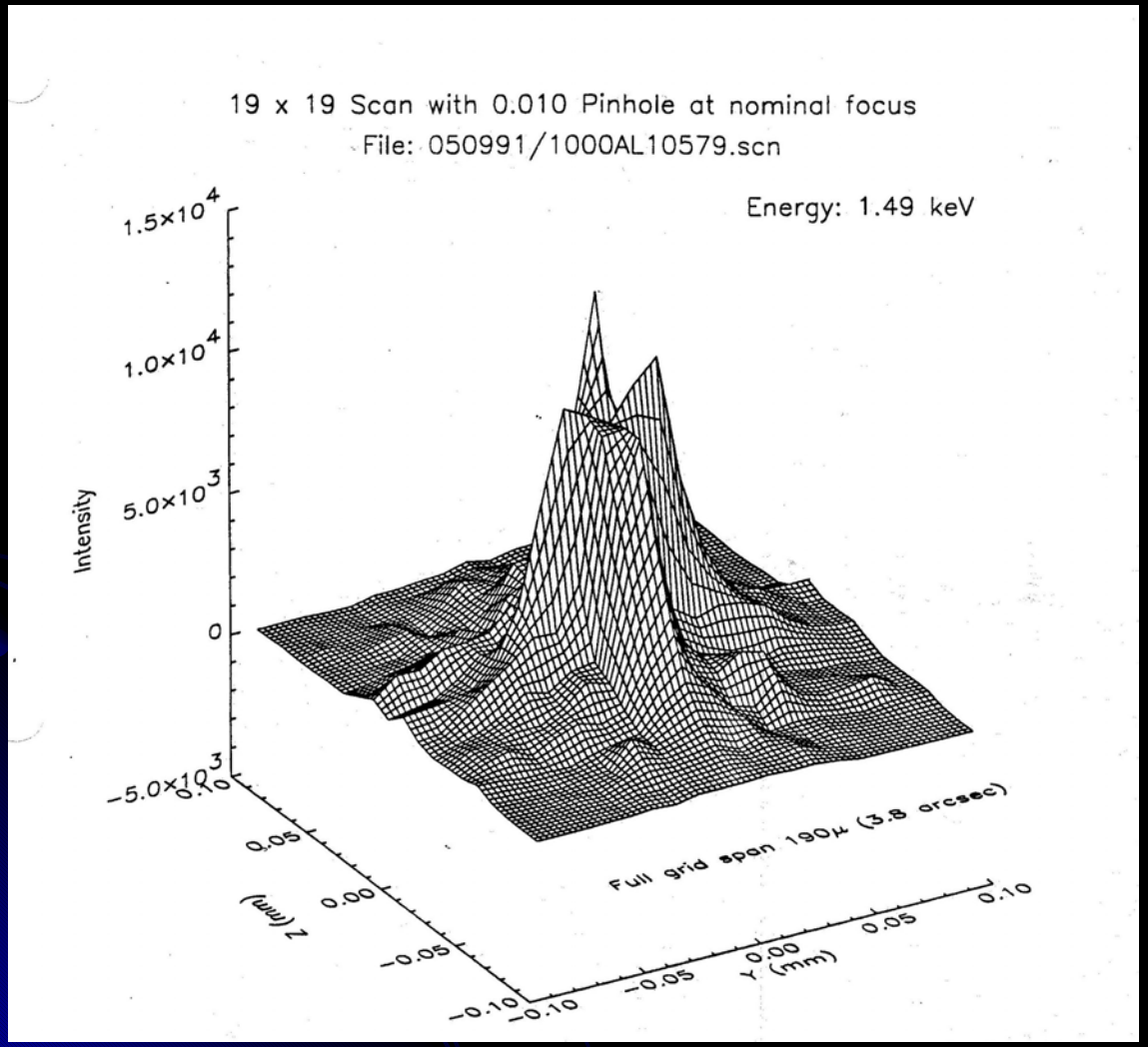


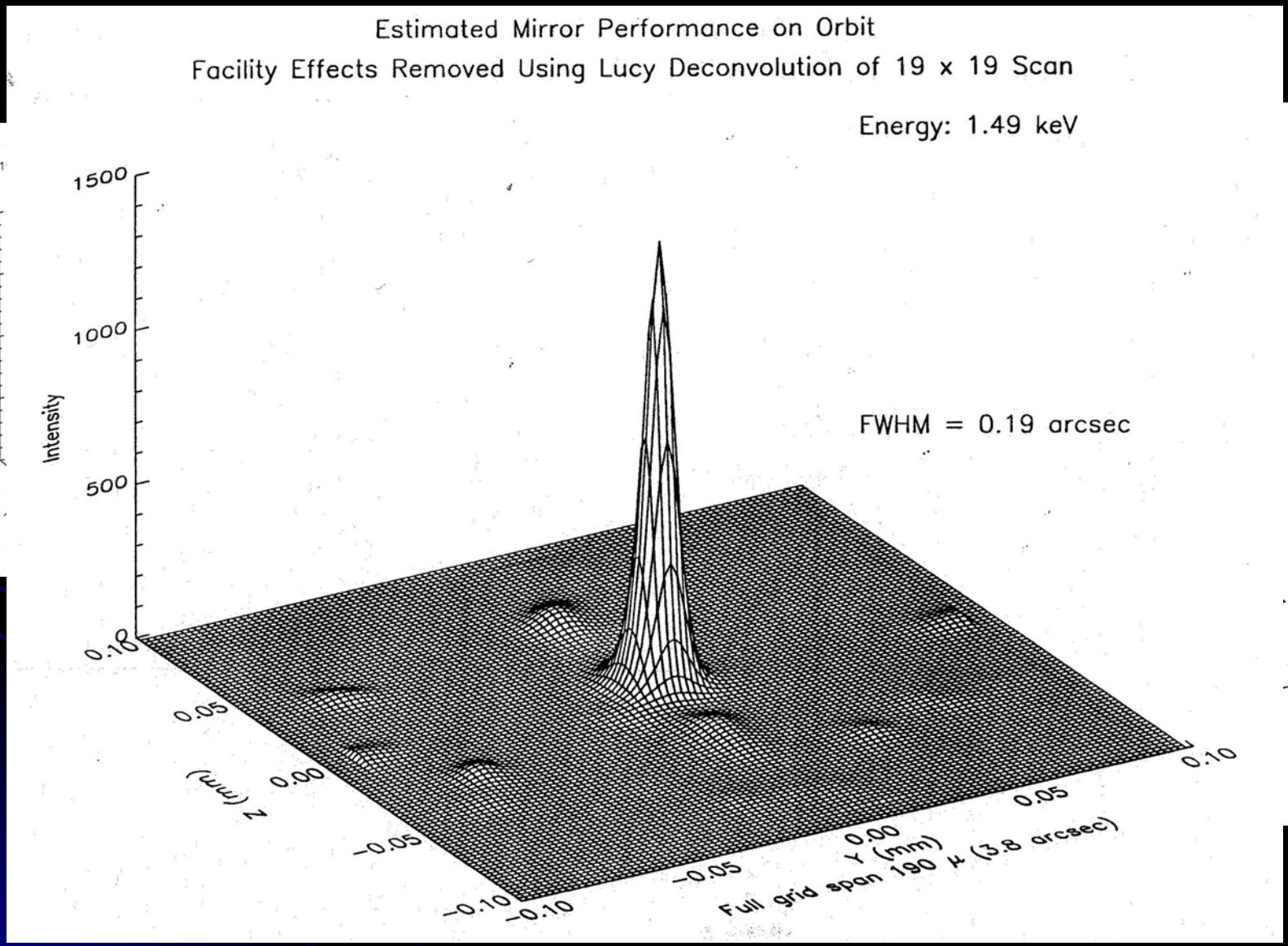


VETA - 1991



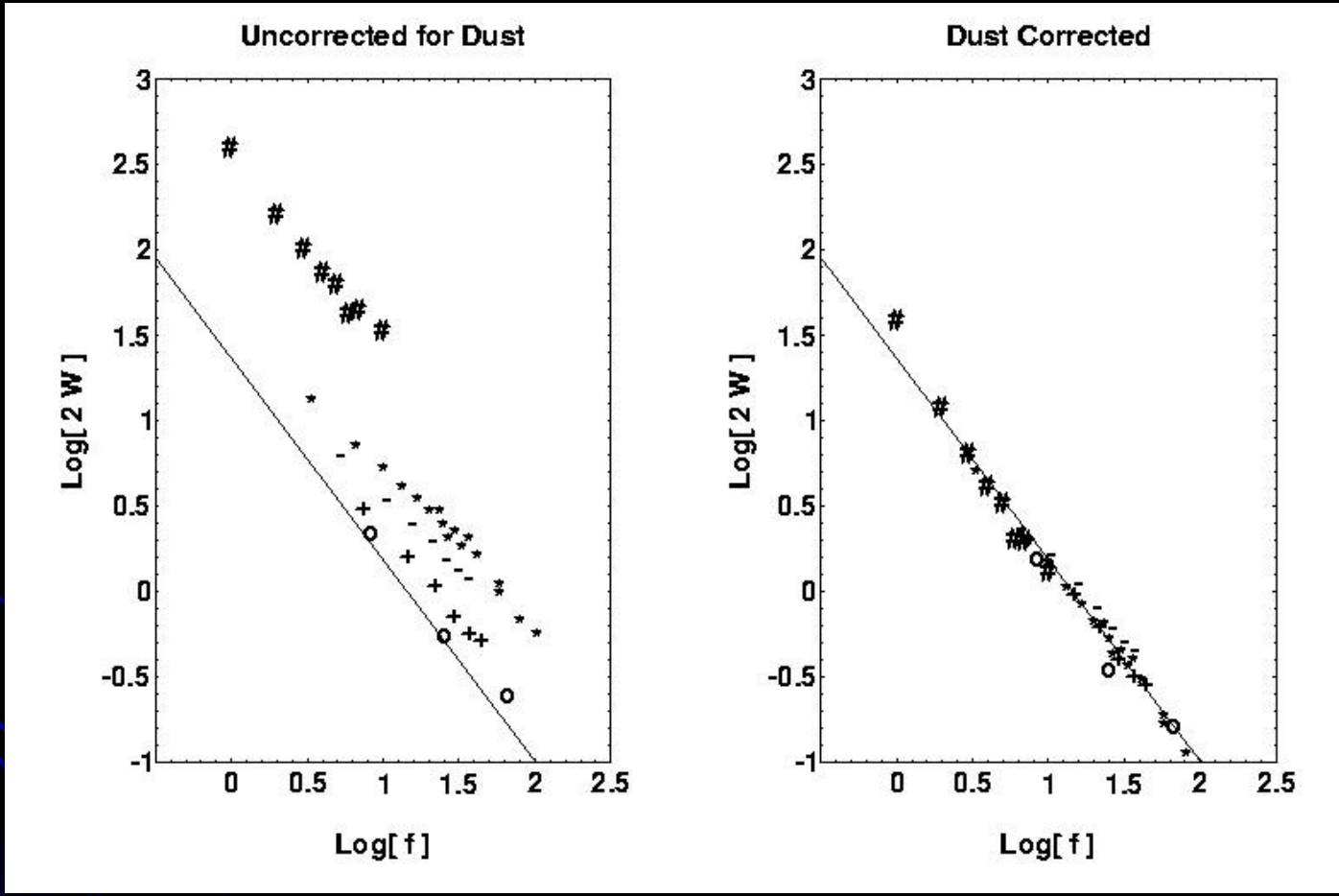
- 1G Effects!

VETA


Estimated Mirror Performance on Orbit
Facility Effects Removed Using Lucy Deconvolution of 19 x 19 Scan
Energy: 1.49 keV
FWHM = 0.19 arcsec
Intensity
1500
1000
500
0
0.10
0.05
0.00
−0.05
−0.10
Z (mm)
Y (mm)
Full grid span 190 μ (3.8 arcsec)

VETA

- Dust!

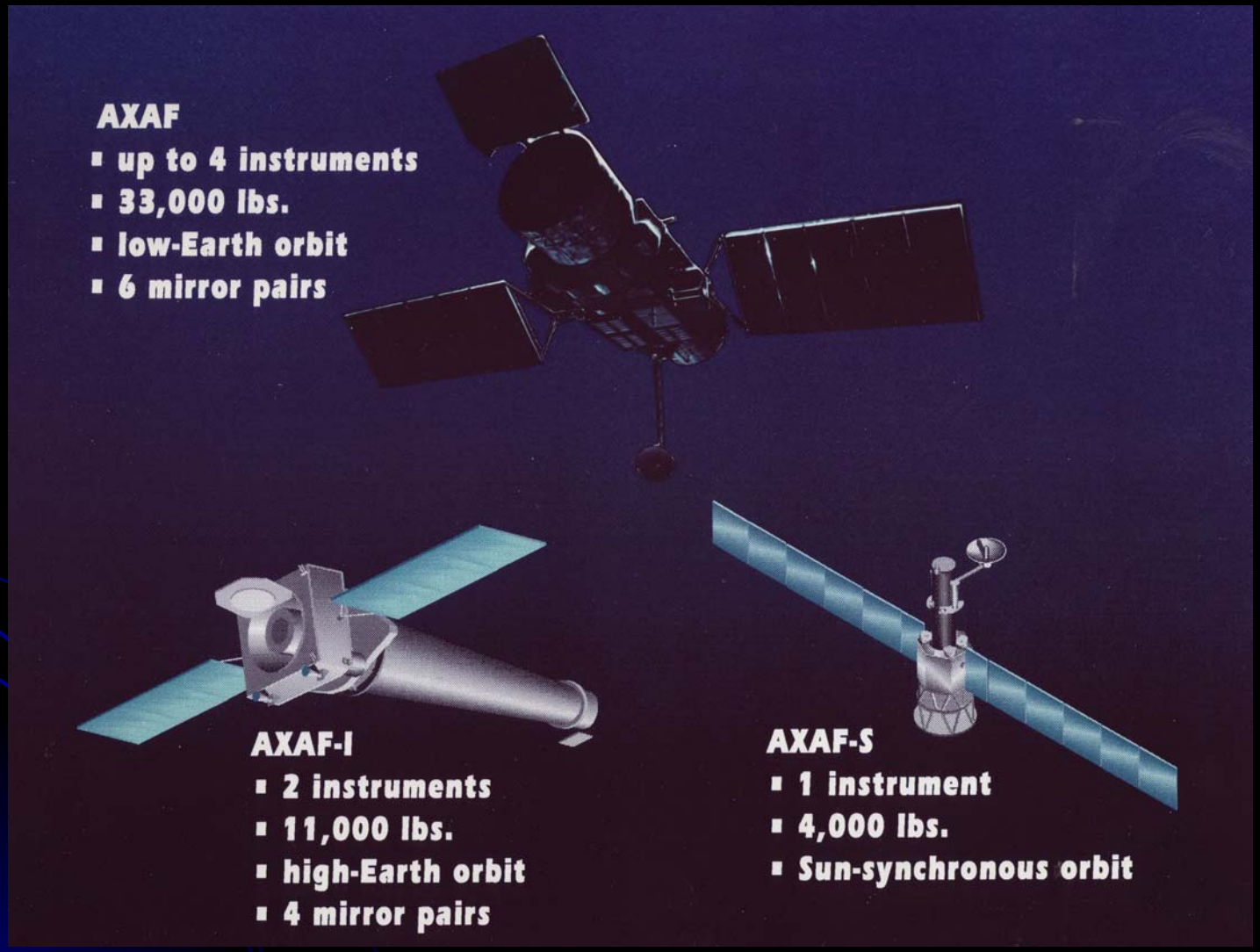


Veta Test Conclusion

Veta Test Conclusion

- We passed the congressional milestone
- But ….

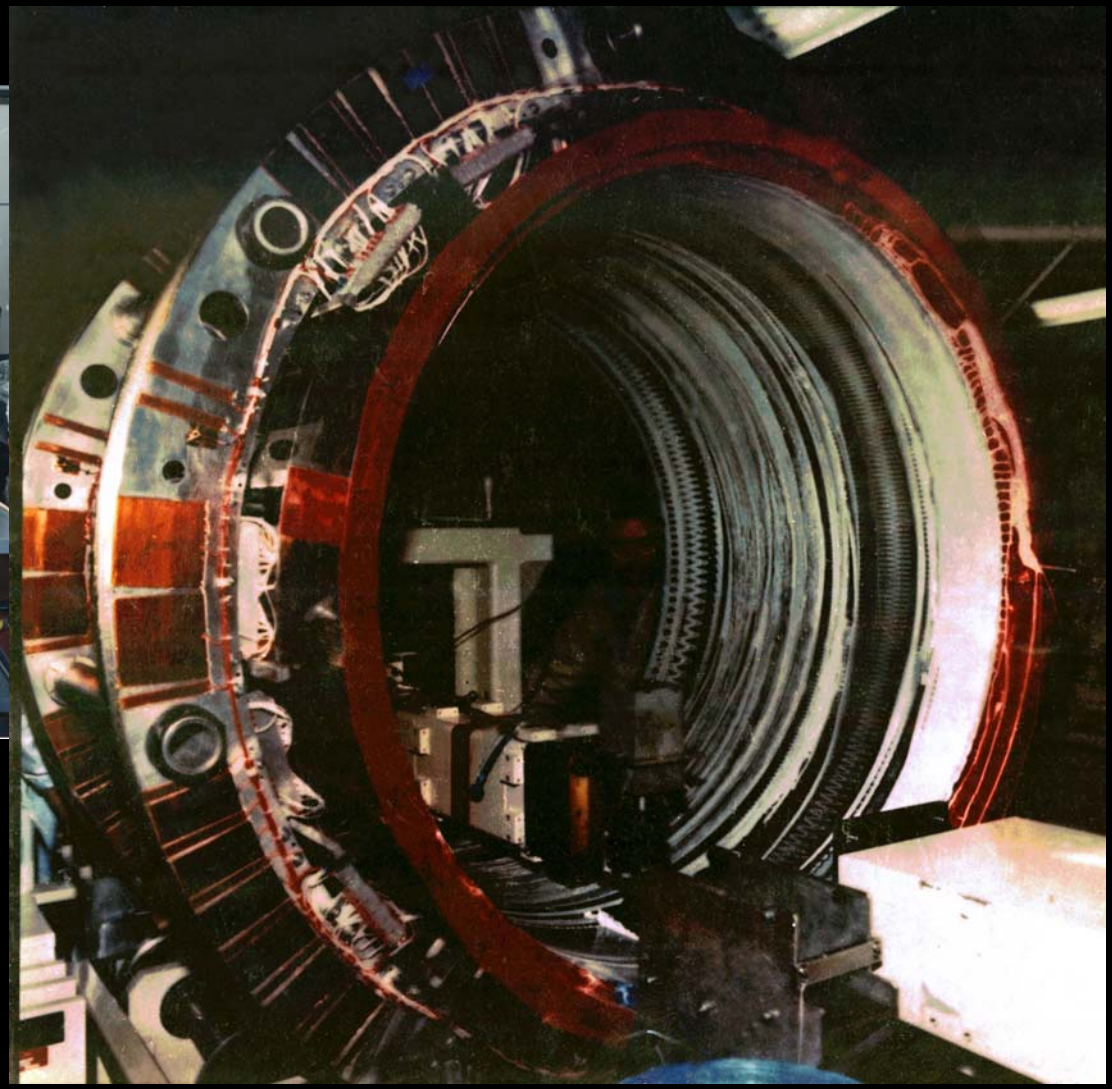
Restructuring - 1992



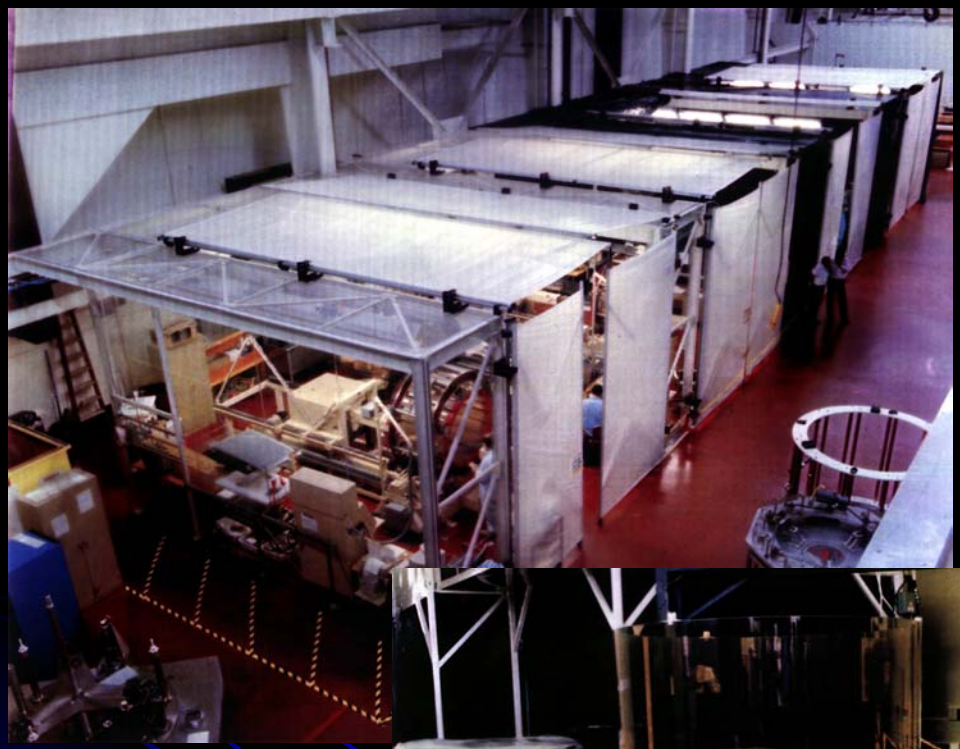
Restructuring

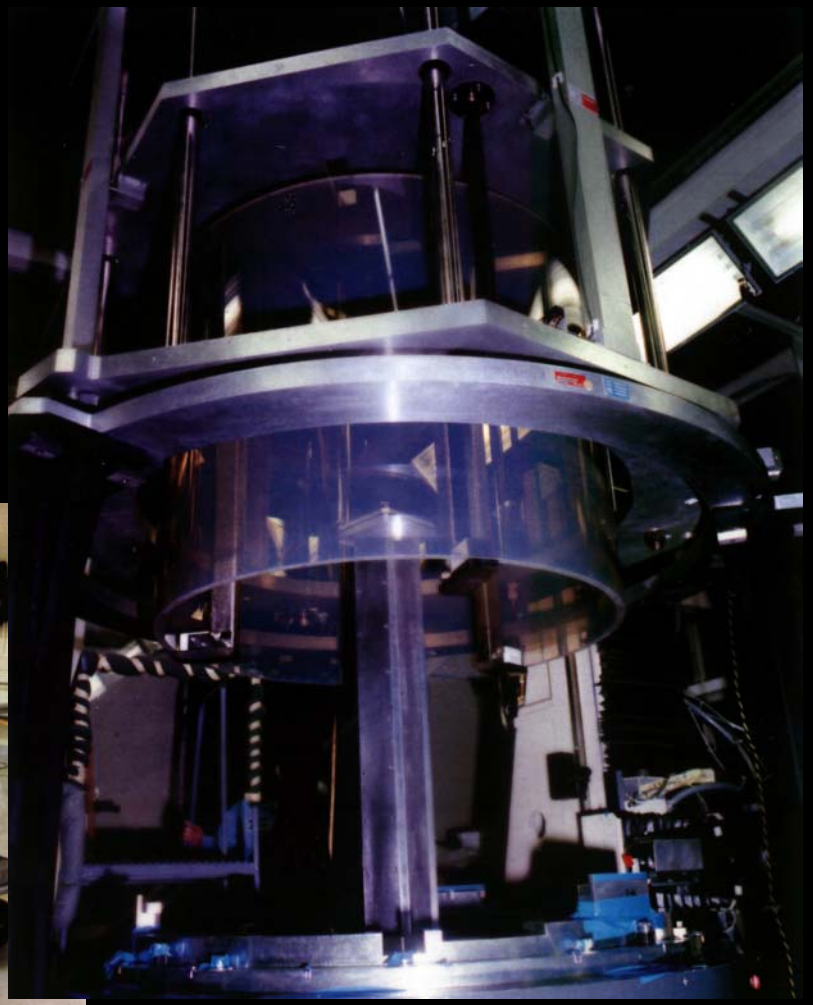
- Servicing Disappears from AXAF-I
  - Assured by new orbit
  - But benefits
    - Efficiency
    - Thermal
    - Iridium
- Loss of two mirrors
- Ultimately “loss” of AXAF-S

Optics

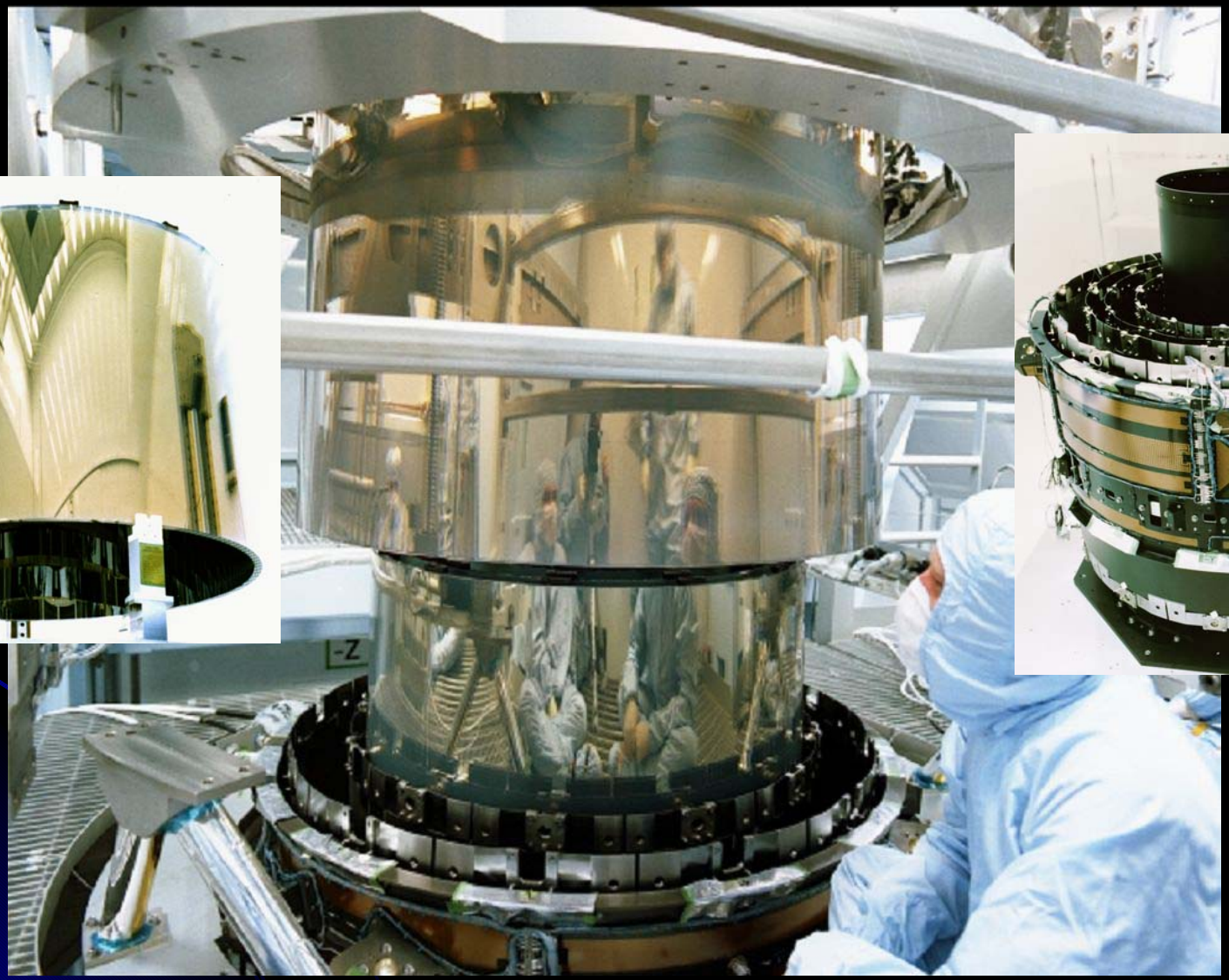


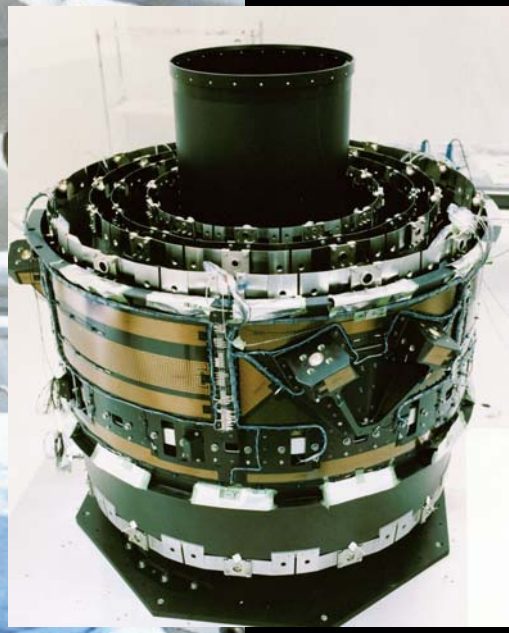
Optics





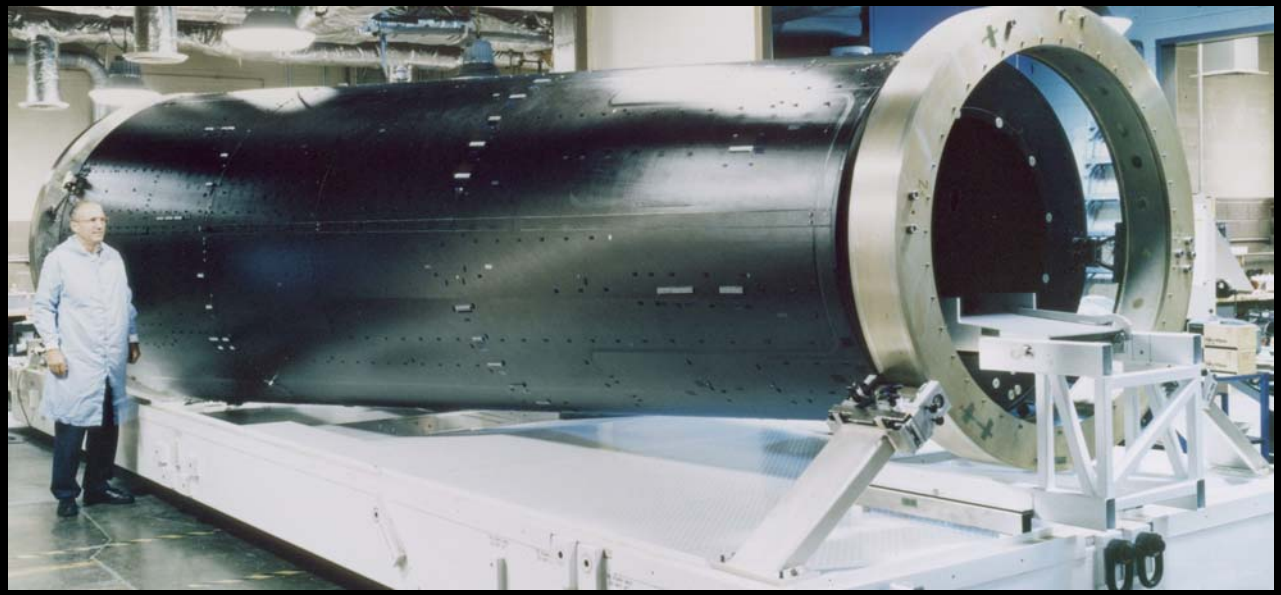
Telescope



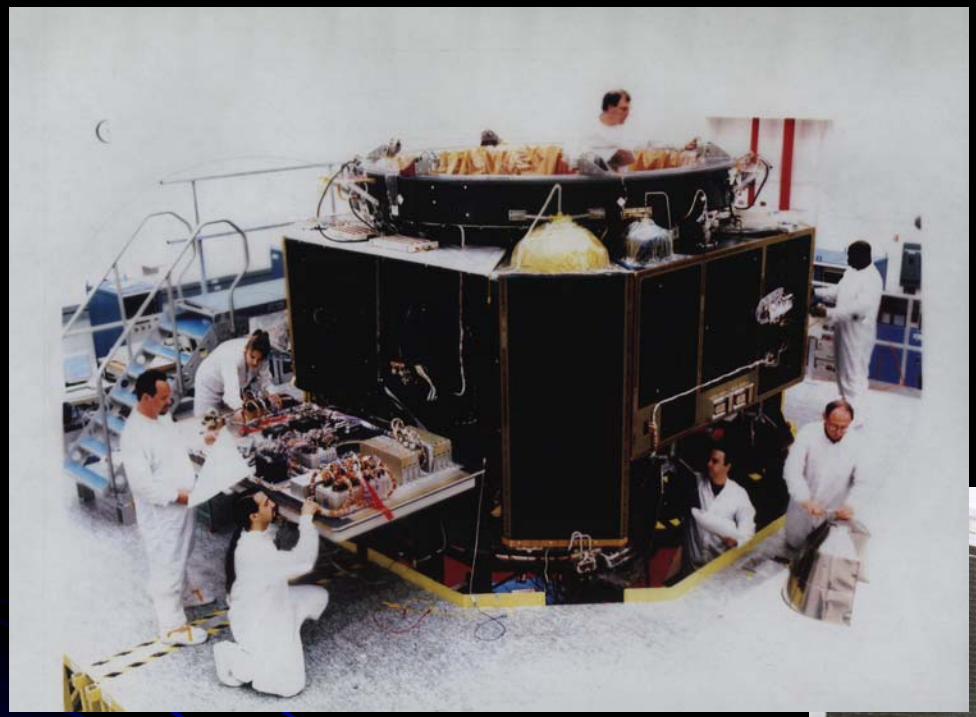


Telescope

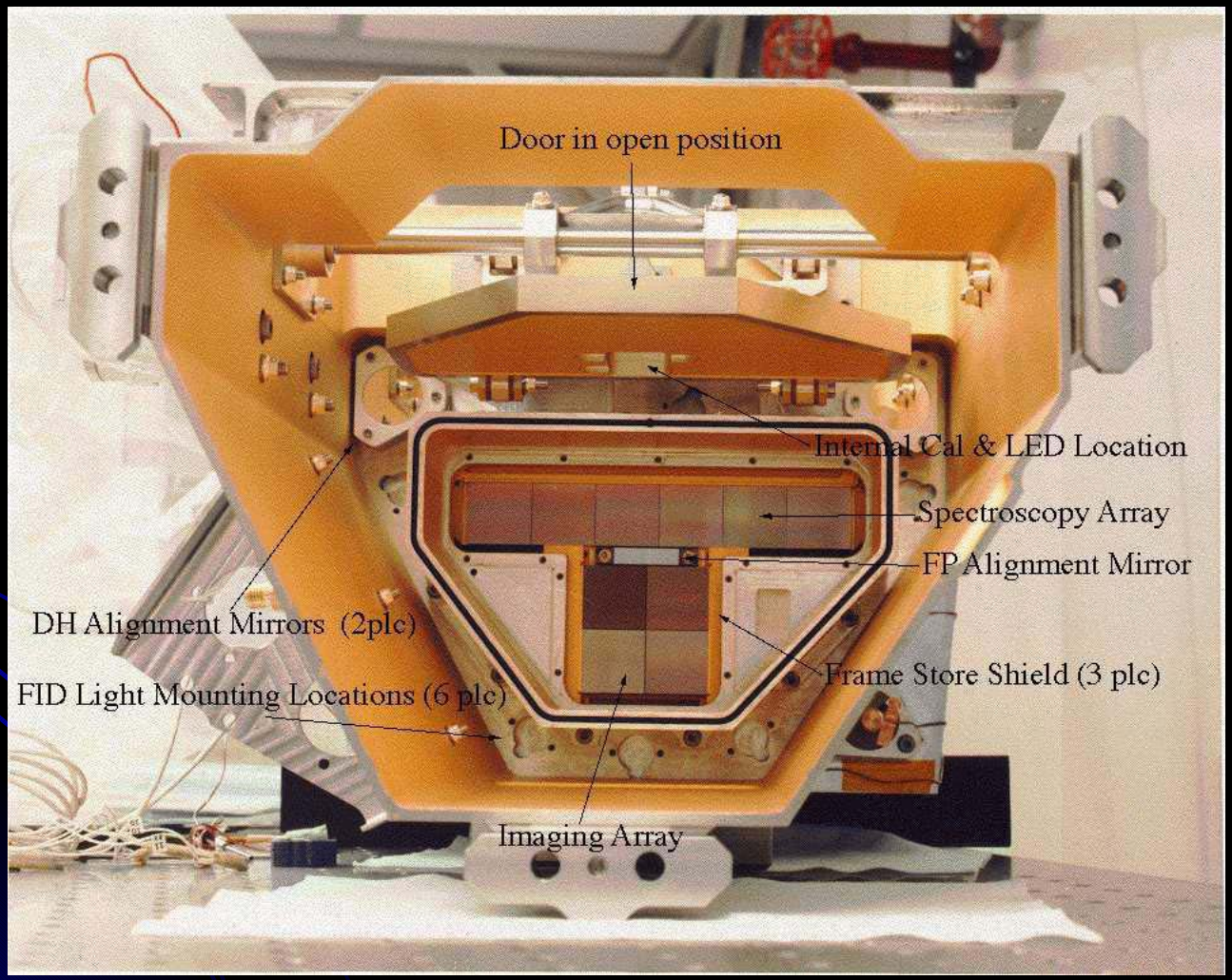
Optical Bench



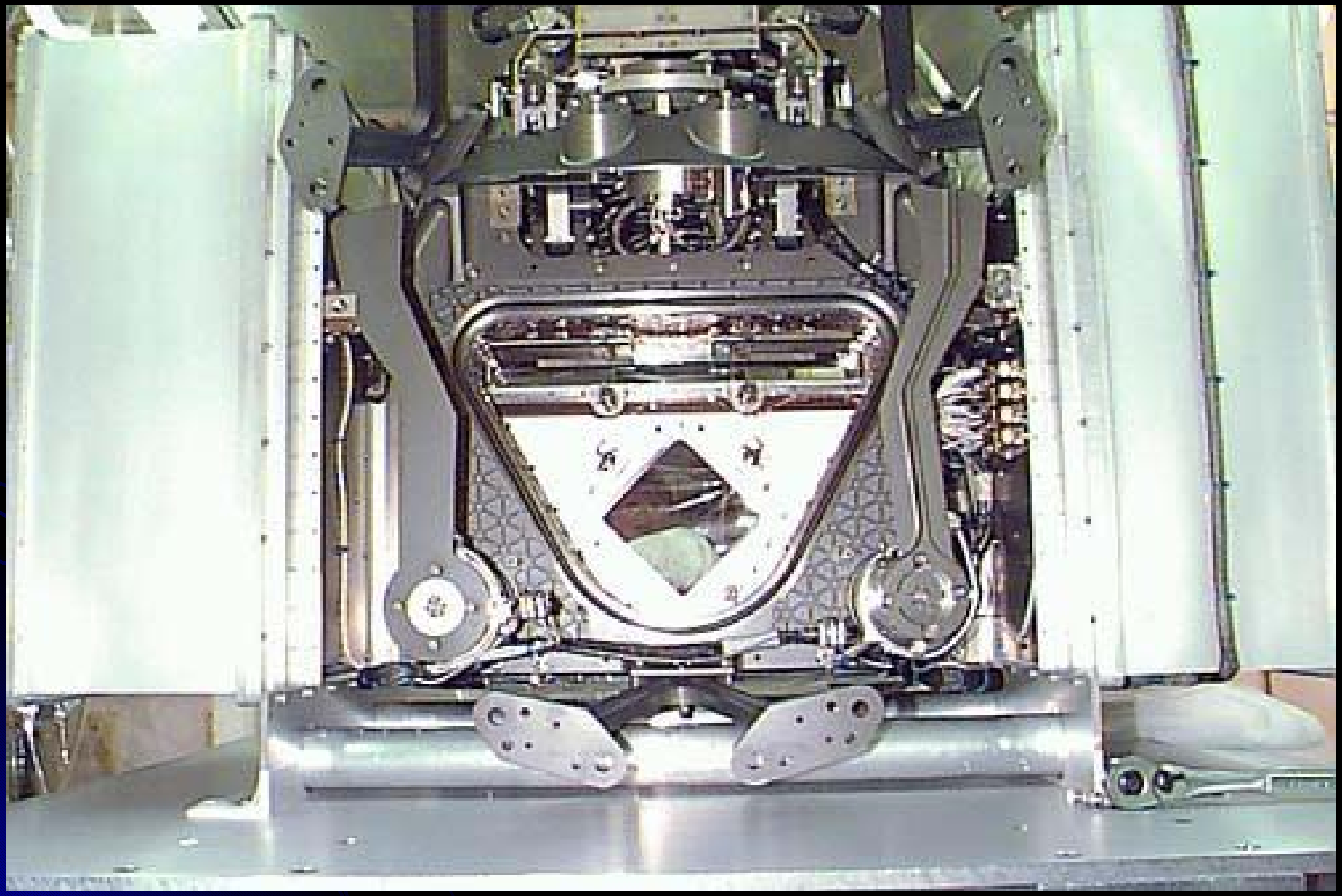
Spacecraft



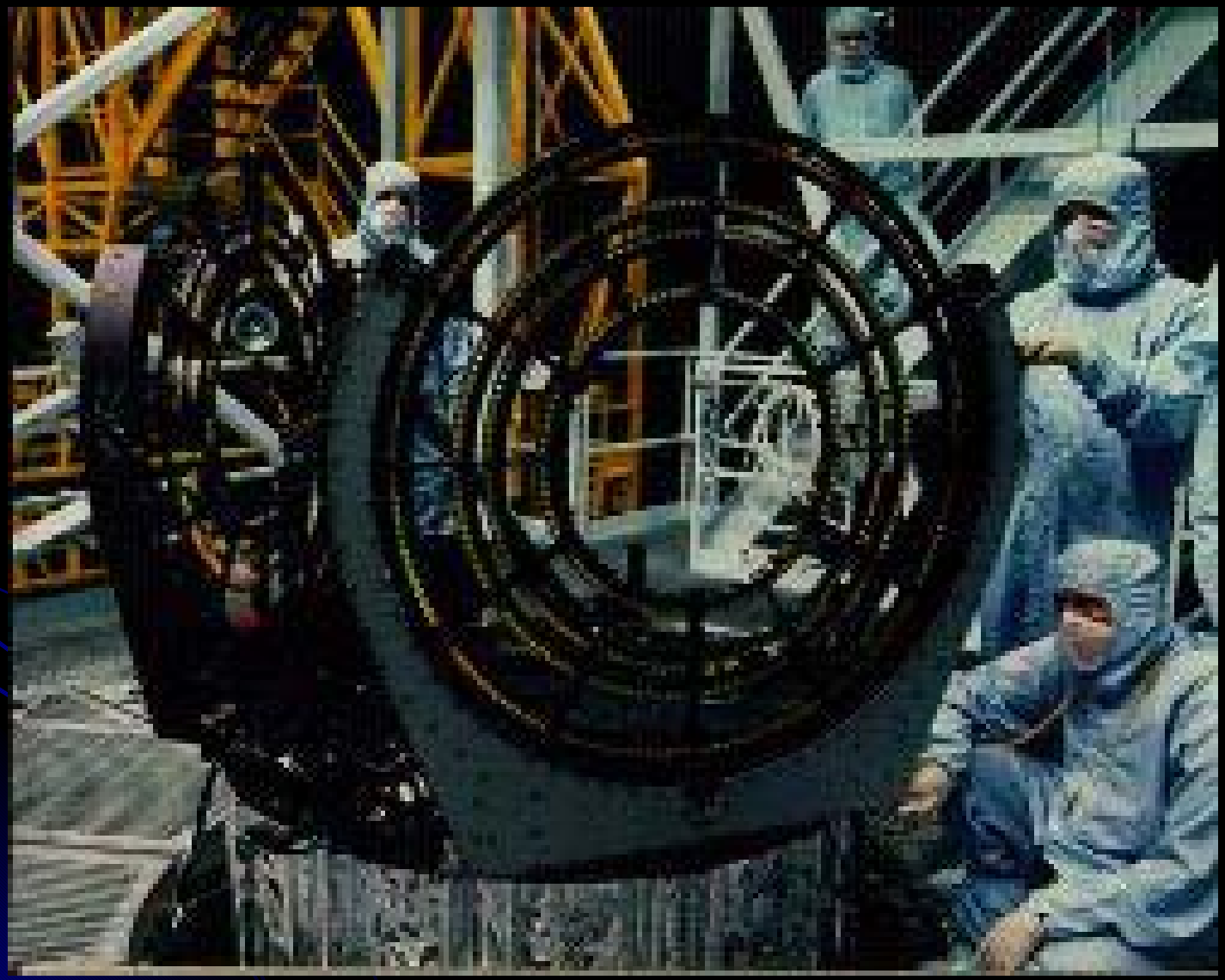
Focal Plane Instruments
ACIS



Focal Plane Instruments
HRC



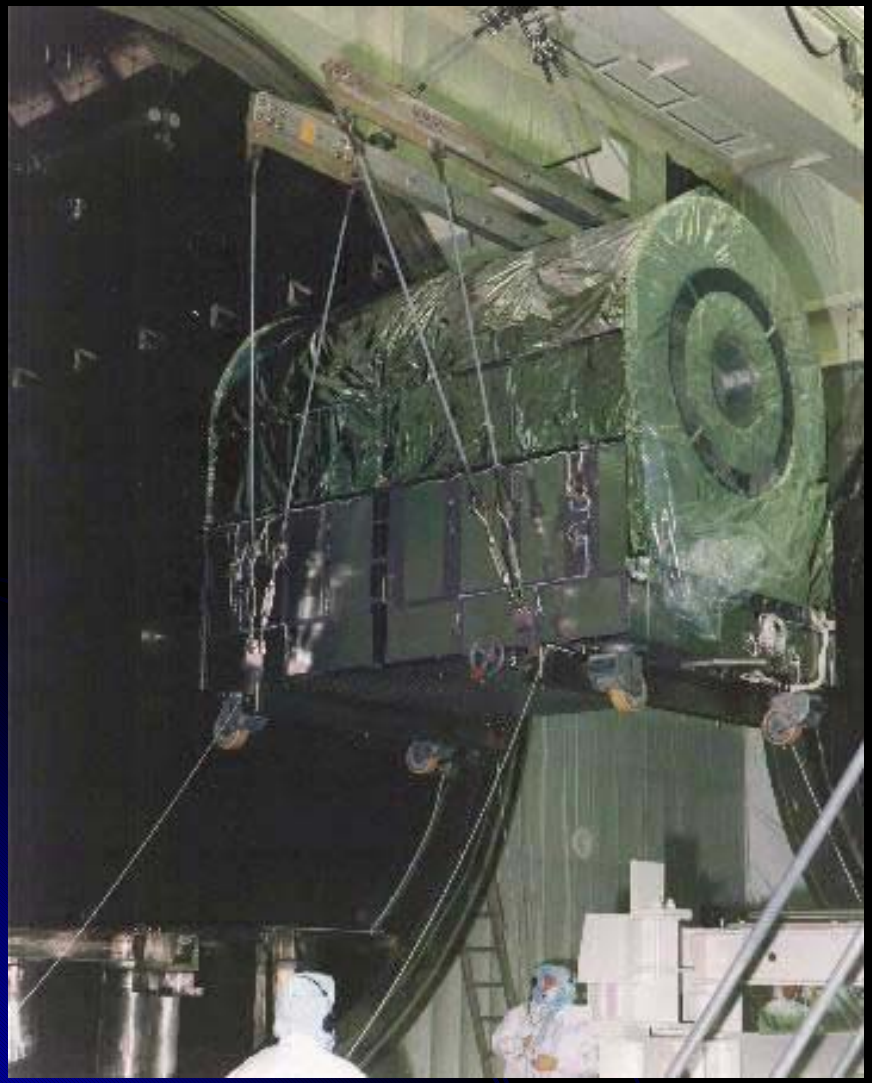
Gratings



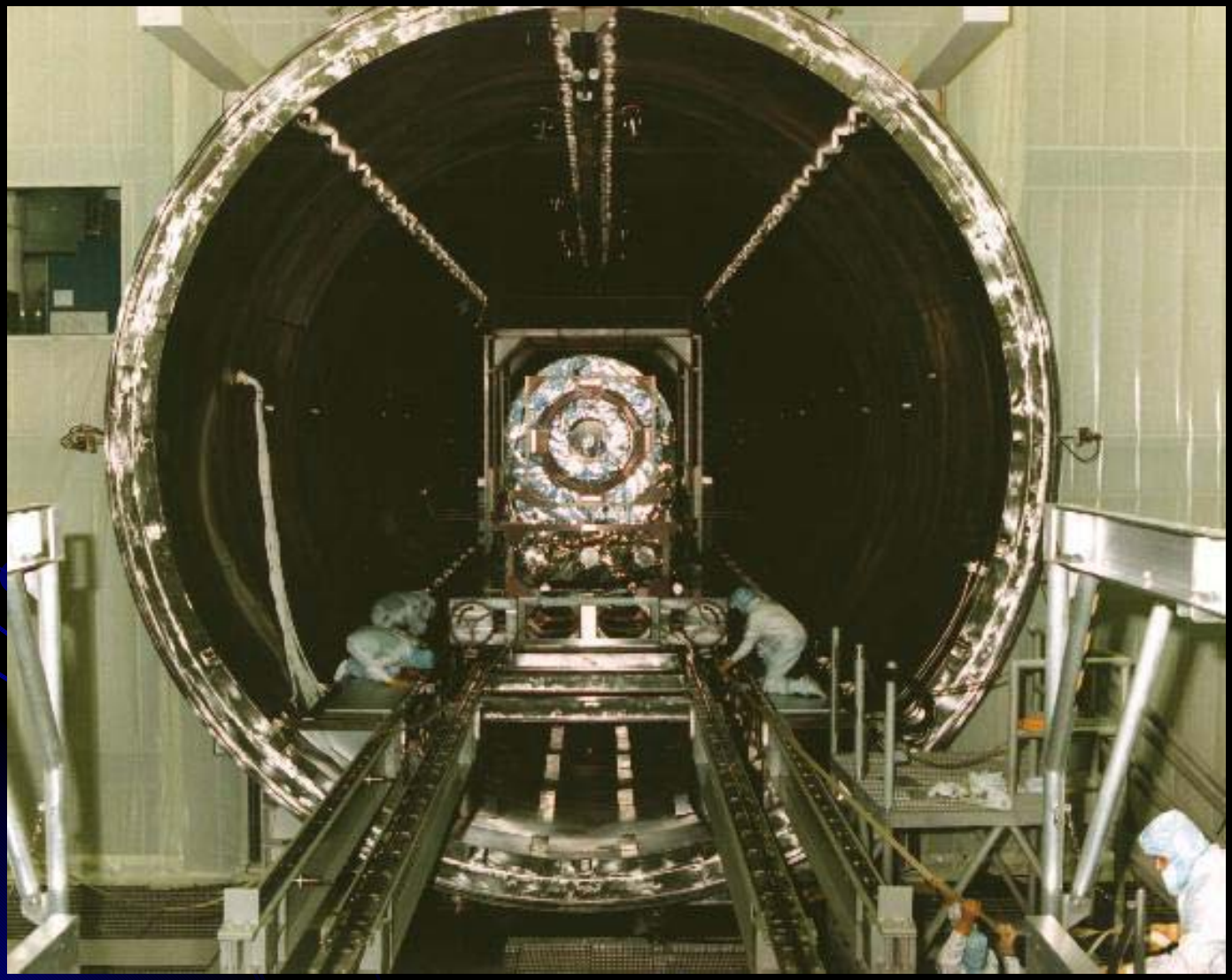
X-Ray Calibration (1996-1997)

X-Ray Calibration

X-Ray Calibration

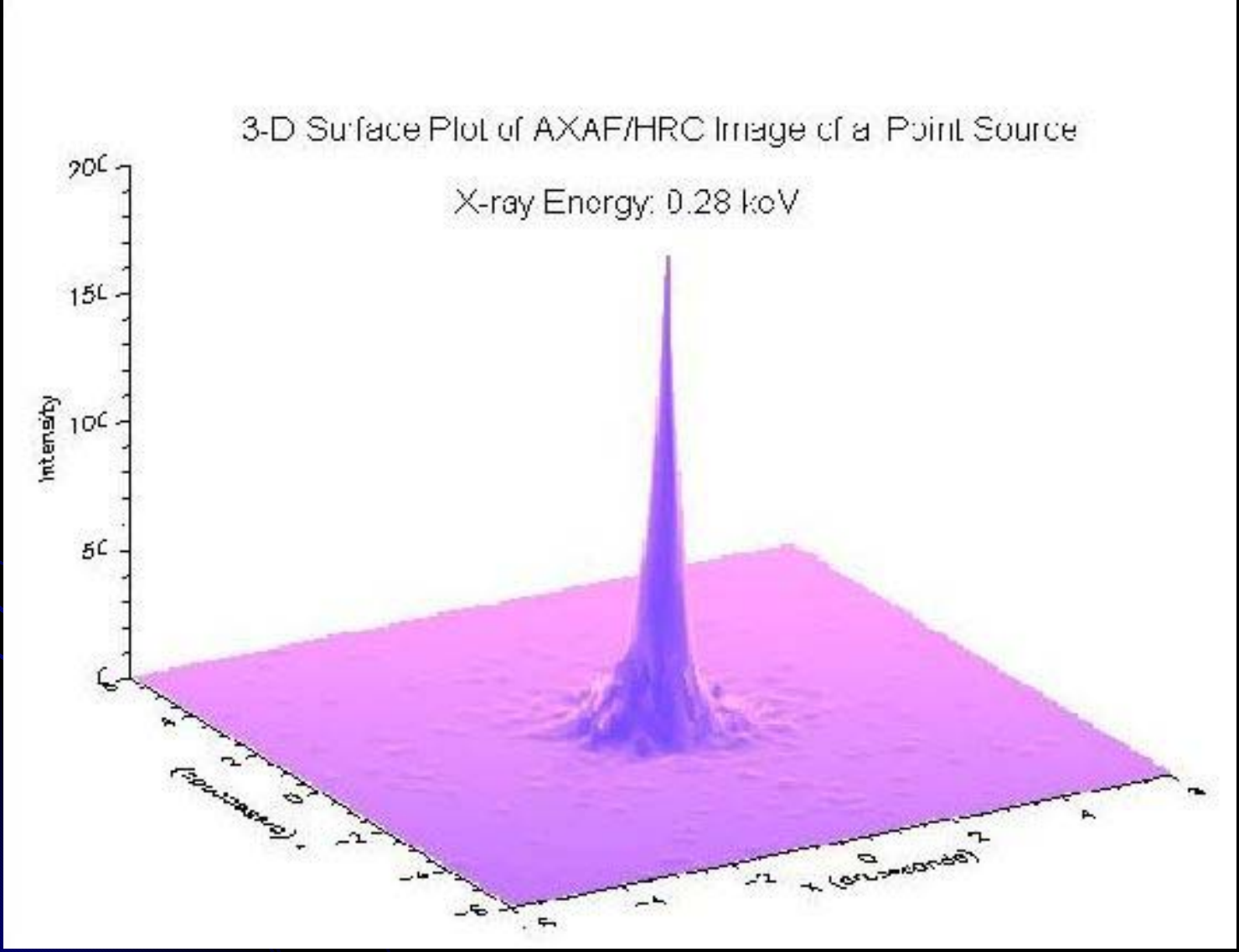


X-Ray Calibration

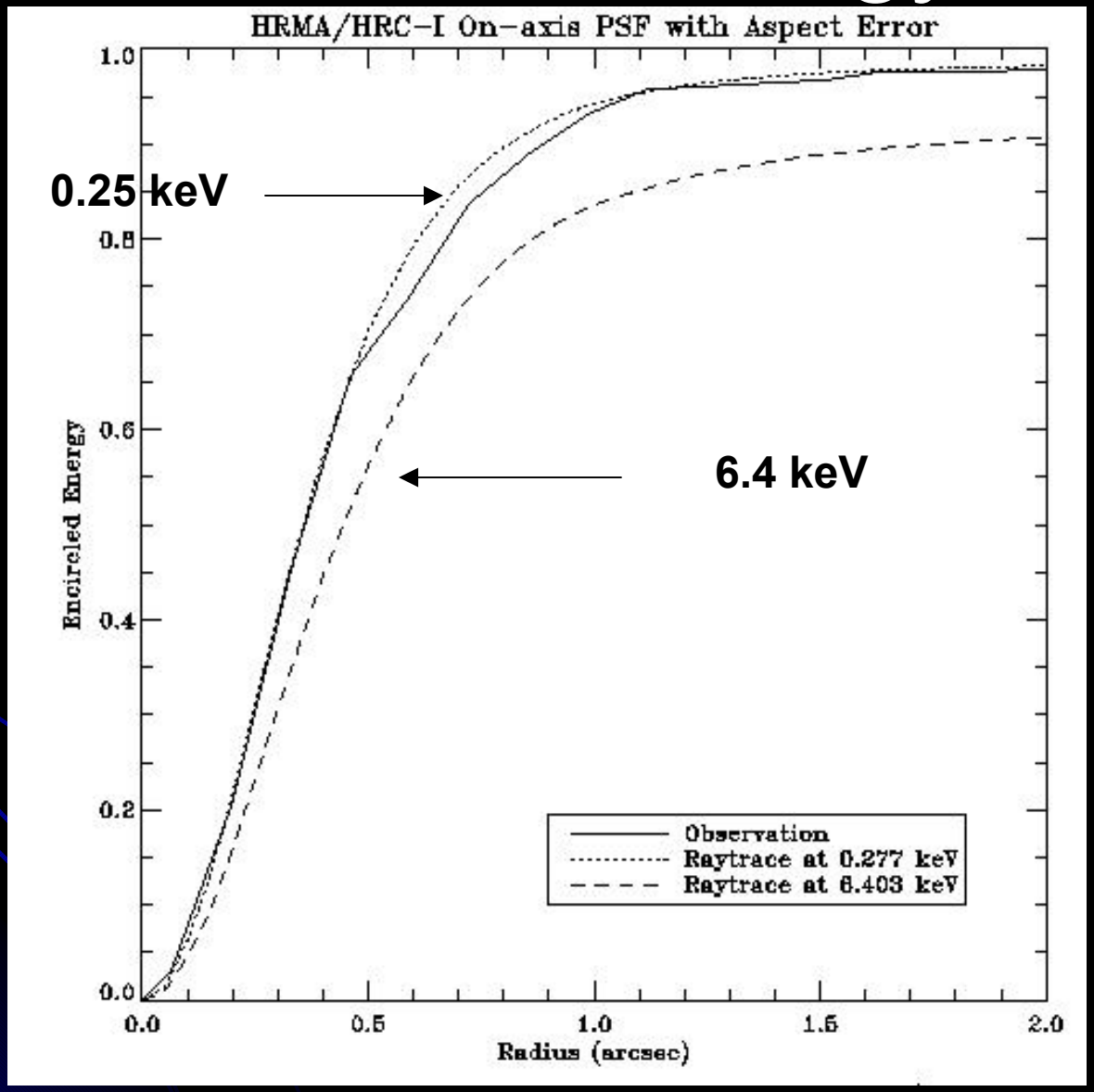


X-Ray Calibration

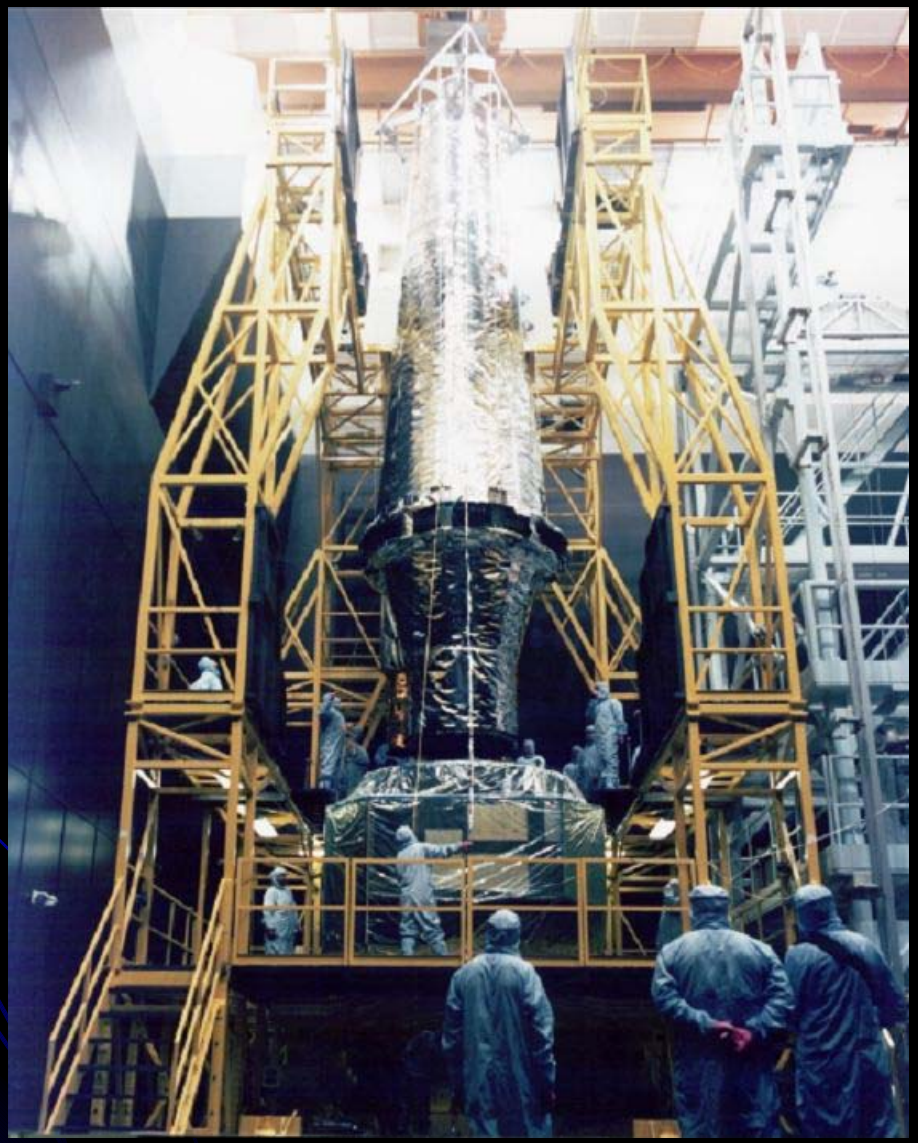
X-Ray Calibration



Encircled Energy

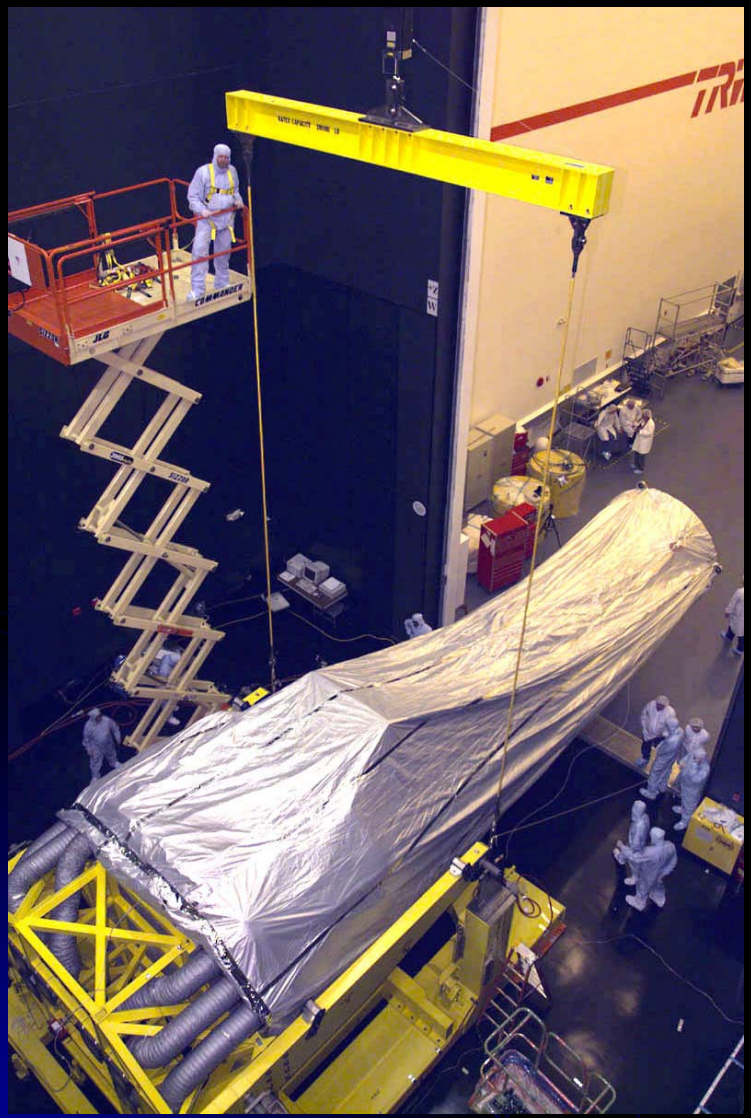


Integration with the S/C



1998

On to the Cape – Feb 1999



With upper stage

Chandra with Chandra

Launching - July 1999

The Launch

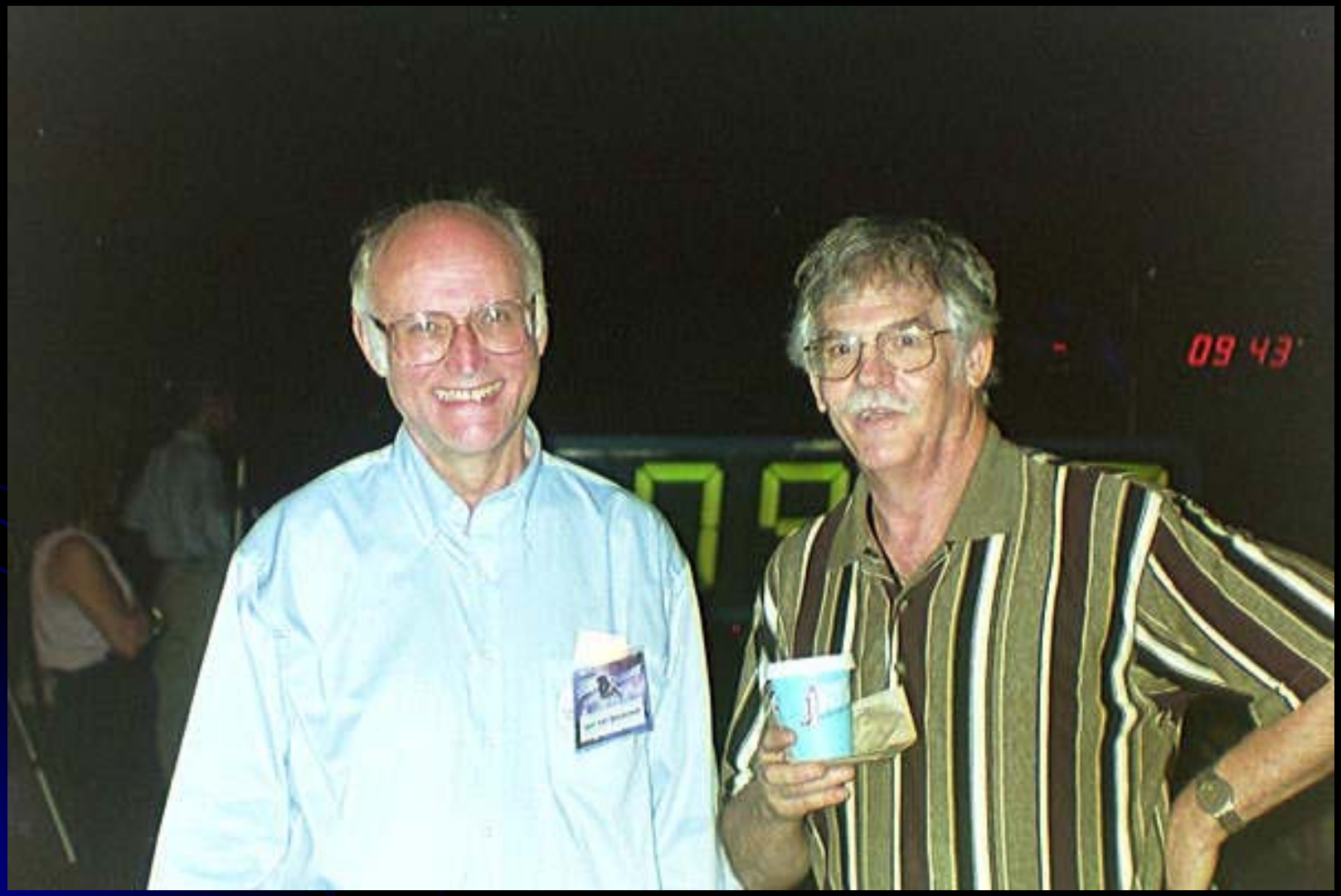
- **Beyond the Sky**
  Words and Music by Judy Collins

"And we will fly beyond the sky
Beyond the stars beyond the heavens
Beyond the dawn we'll carry on
Until our dreams have all come true
To those who fly - we sing to you"

Three Launch Attempts

- Mon/Tue July 19/20
  - Sensor spike hydrogen in the engine compartment
- Wed/Thurs July 21/22
  - Lightening in the vicinity
- Thurs/Fri July 22/23
  - Third time is a charm

Before Launch Attempt 1

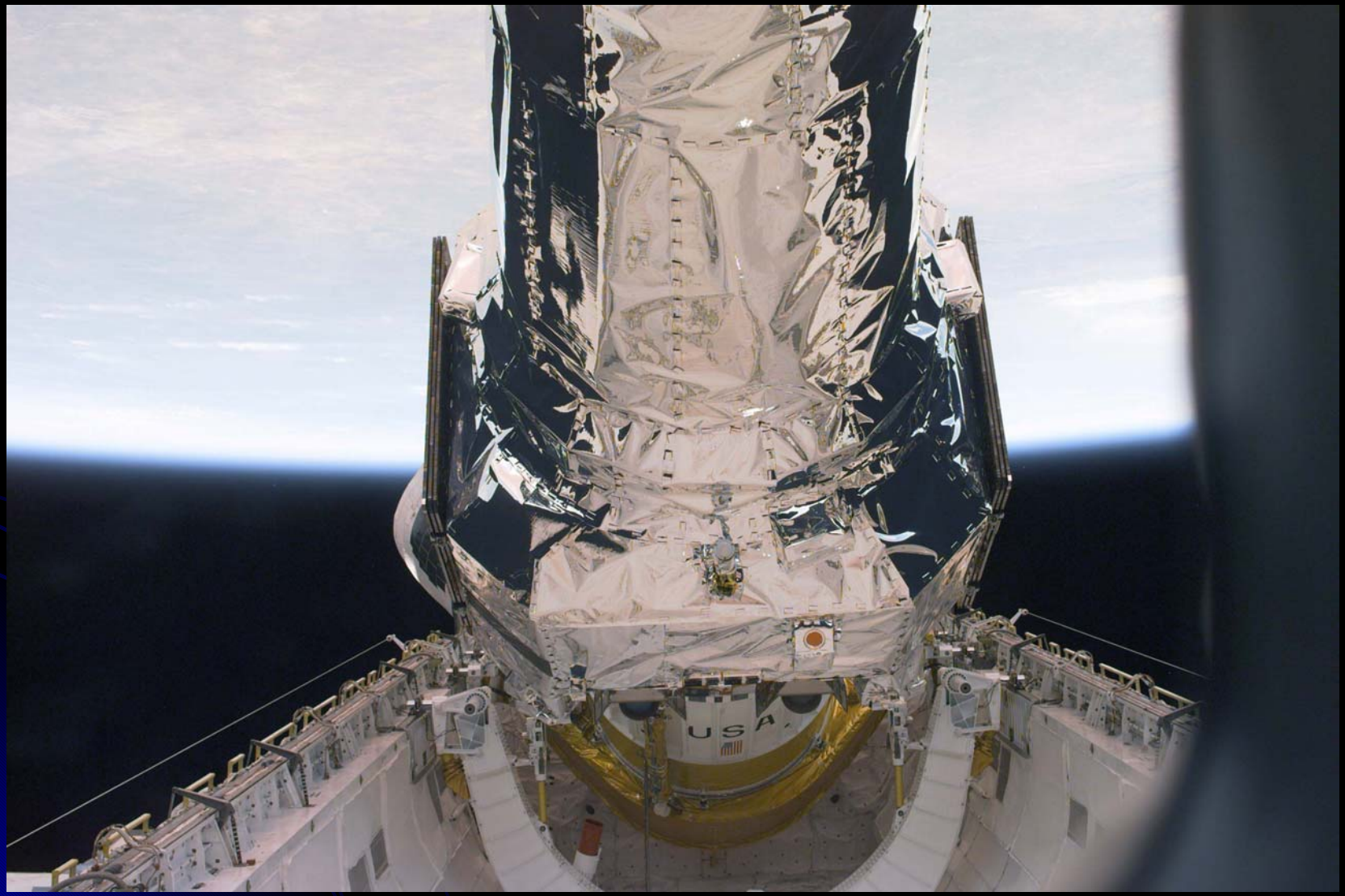


Launch

July 23 1999 @ 12:31 a.m. EDT

In Cargo Bay

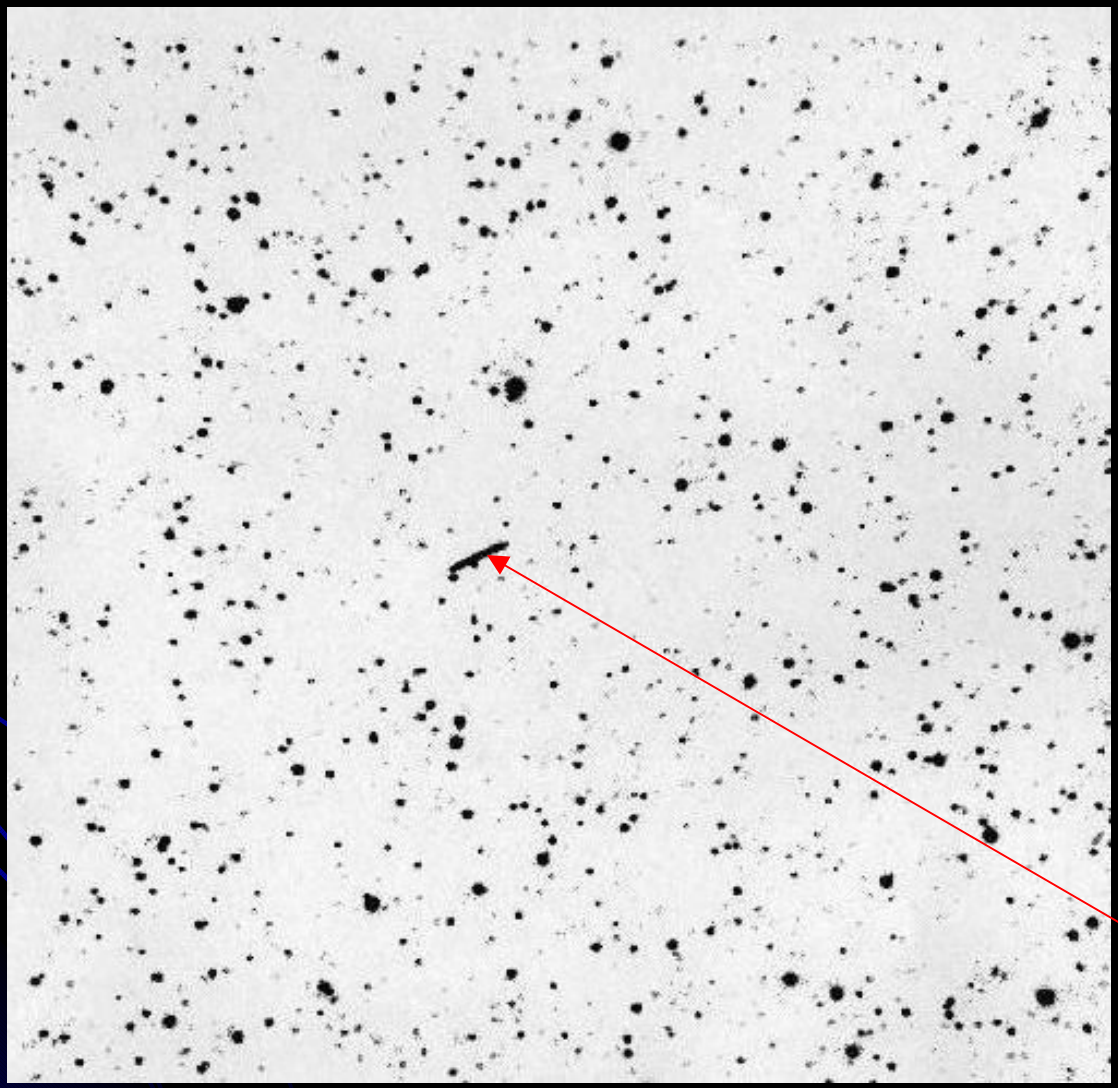
Just Prior to Deployment



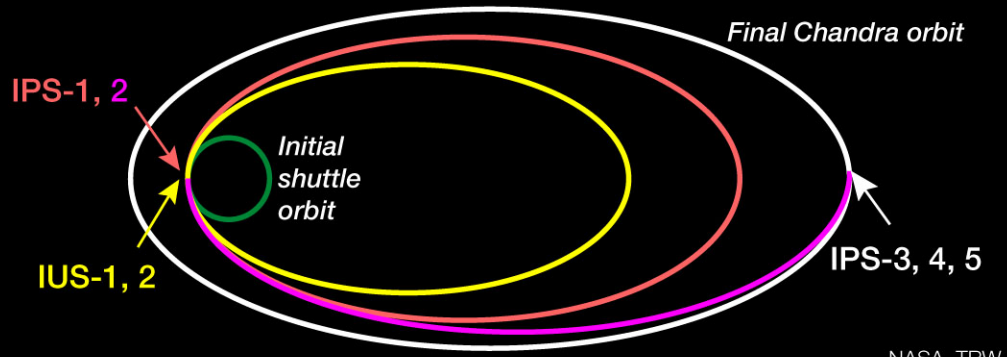
Deployment – The Movie

Deployed!

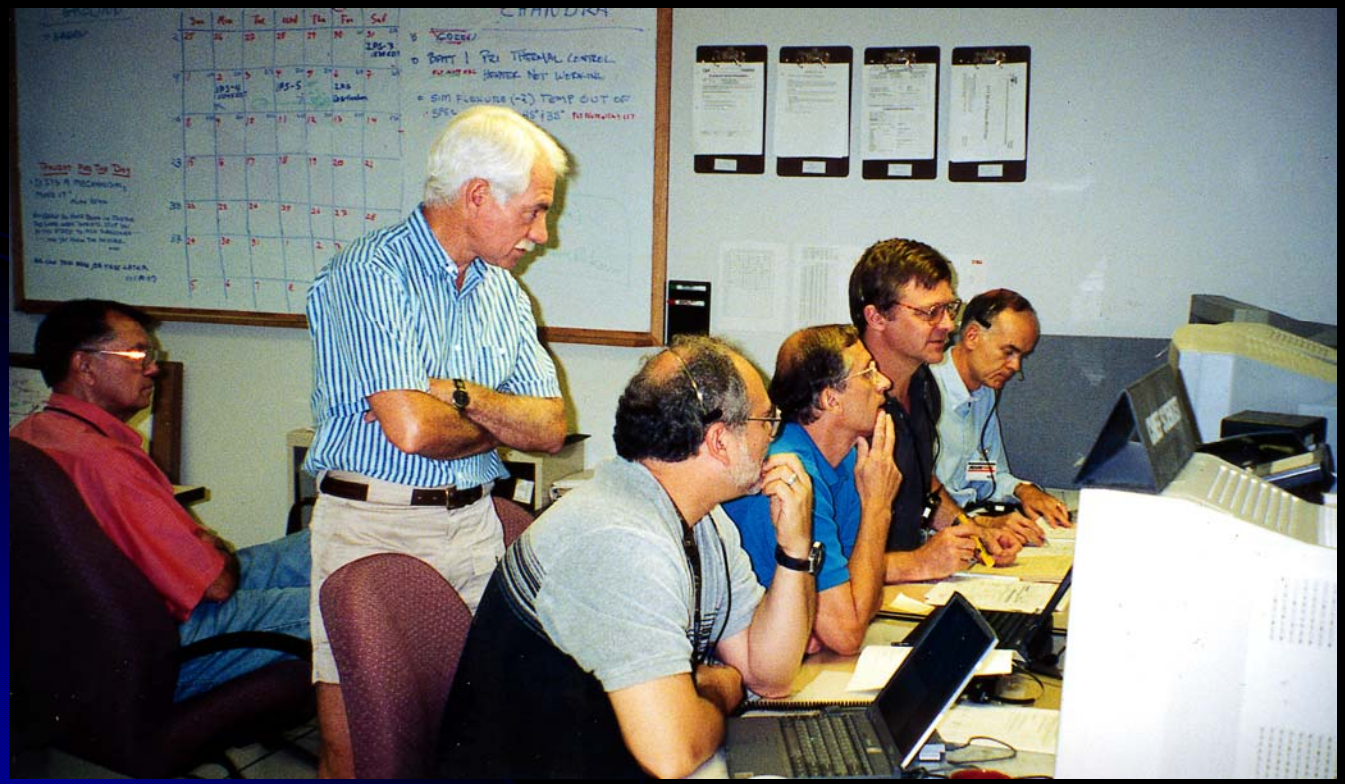
Chandra In Orbit!



Sitting in the Control Center



NASA, TRW



Burns

- July 24 (Saturday)
- July 25 (Sunday)
- July 31 (Saturday)
- August 5 (Thursday)
- August 7 (Saturday)

Door Openings

- July 26 - HRC Housing
- August 8 – ACIS Housing
  - Had failed during ground test
  - 18º would indicate the seal was broken
  - 70º reading was fully open

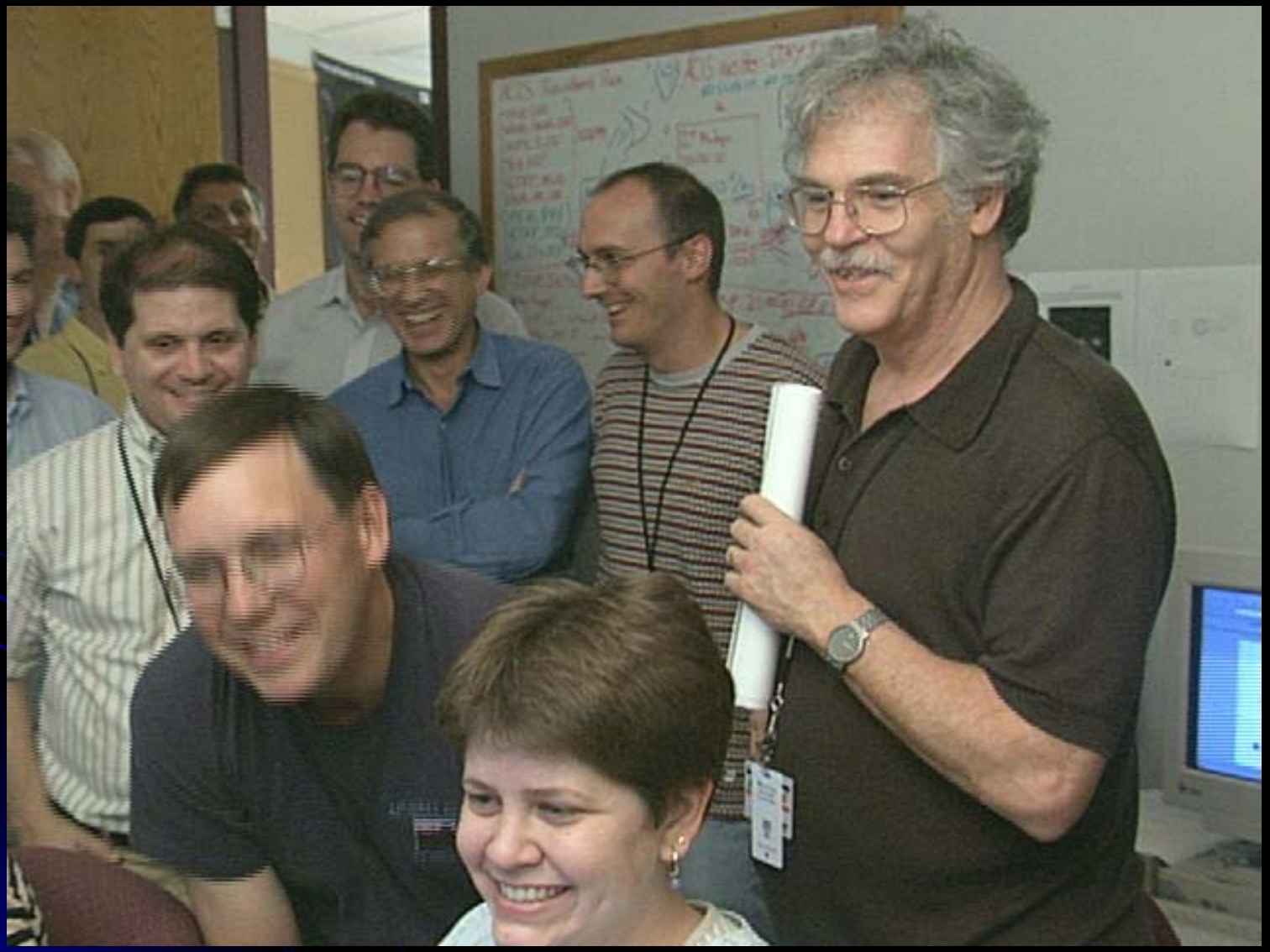
Pulse 1 - no motion
Pulse 2 - 13º
Pulse 3 - 19.5º
Pulse 4 - 36º
Pulse 5 – 71.5º

Door Openings (continued)

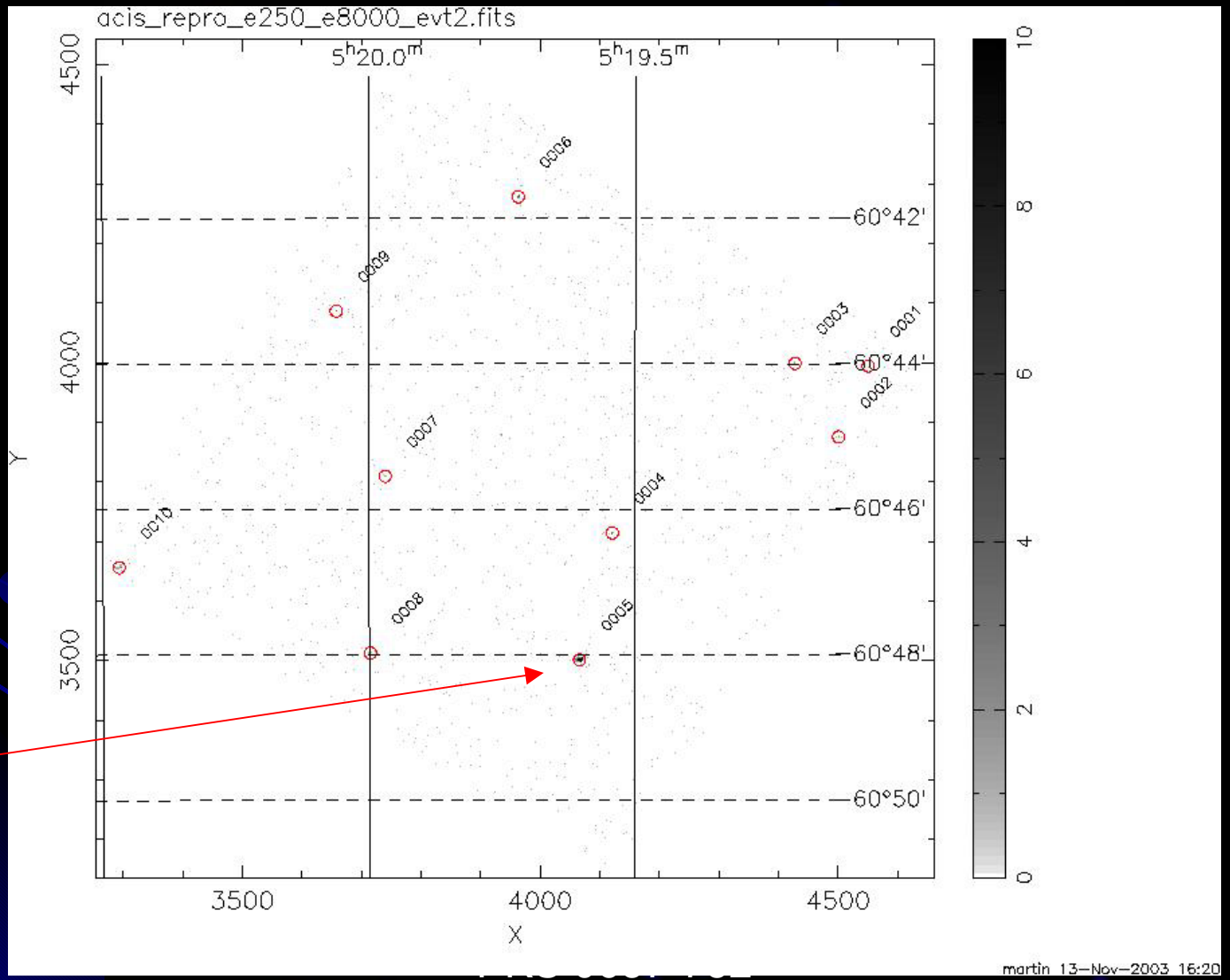
- August 11 – HRMA aft cover
- August 12 – HRMA forward cover

First Light

Chandra First Light



Chandra First Light



Leon X-1

The Nobel Prize - 2002

4-Year Symposium